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ABSTRACT

Abstracts of research which has been carried on during the 1972-73 academic year at the Computer and Information Science Research Center at Ohio State University are presented. Part 1 describes the center's organizational structure, objectives, scope, facilities, programs, and recent technical reports. The remaining eight parts of the document summarize research in: information storage and retrieval; human information processing; information analysis; artificial intelligence; information processes in physical, biological, and social systems; mathematical techniques; systems programing and joint programs. The appendix lists the computer and information science course listings, center faculty, senior personnel, seminar series, related activities, publications, and finally, its technical report series. (WCM)

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# ABSTRACTS OF RESEARCH

JULY 1972 - JUNE 1973

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The Computer and Information Science Research Center

The Ohio State University

Columbus, Ohio 43210

## FOREWORD

The Computer and Information Science Research Center at The Ohio State University is an interdisciplinary research organization which consists of the faculty, staff and graduate strudents of many University departments and laboratories. Most of these activities take place in our Department of computer and Information Science.

This publication contains the abstracts of research which has been carried on during the 1972 - 1973 academic year. This research has been supported in part by grants from agencies such as the National Science Foundation, the U.S. Air Force Office of Scientific Research, the Office of Naval Research and other governmental agencies as well as by the University. Copies of research reports published by the Center may be obtained by writing to the Computer and Information Science Research Center, The Ohio State University, 2024 Neil Avenue, Columbus, Ohio, 43210.

Marshall C. Yovits
Director, Computer and
Information Science Research Center

TABLE OF CONTENTS


| | Page |
|---|---|
| FOREWARD | |
| I. THE OHIO STATE UNIVERSITY COMPUTER AND INFORMATION SCIENCE RESEARCH CENTER | |
| ORGANIZATIONAL STRUCTURE | 1 |
| OBJECTIVES OF THE CENTER | 1 |
| SCOPE OF THE PROGRAM | 2 |
| FACILITIES | 2 |
| ACADEMIC PROGRAMS IN COMPUTER AND INFORMATION SCIENCE | 4 |
| Organization of The Department of Computer and Information Science | 4 |
| Objectives of The Department | 4 |
| Undergraduate Programs | 4 |
| Growth of The Department of Computer and Information Science | 5 |
| Graduate Programs | 6 |
| Course Offerings | 7 |
| Faculty | 7 |
| INTERACTION WITHIN THE UNIVERSITY | 7 |
| INTERACTION WITHIN THE INFORMATION SCIENCE COMMUNITY | 8 |
| DOCTOR OF PHILOSOPHY DEGREE | 8 |
| RECENT TECHNICAL REPORTS | 9 |
| II. INFORMATION STORAGE AND RETRIEVAL | |
| AUTOMATIC INDEXING (A. E. Petrarca, W. M. Lay, W. S. Stalcup) | 10 |
| A SEQUENTIAL-ANALYSIS CLASSIFICATION TECHNIQUE (J. E. Rush, L. J. White) | 11 |
| III. HUMAN INFORMATION PROCESSING | |
| TRANSFER PROCESSING IN MEMORY (R. L. Ernst, S. Hepler) | 11 |
| IV. INFORMATION ANALYSIS | |
| A GENERAL THEORY OF INFORMATION FLOW AND ANALYSIS (M. C. Yovits, J. G. Abilock) | 12 |

## V. ARTIFICIAL INTELLIGENCE

AUTOMATIC THEOREM PROVING (B. Chandrasekaran, D. Gelperin) 14

DECISION THEORY FOR PATTERN RECOGNITION (B. Chandrasekaran, A. K. Jain) 14

DIMENSIONALITY REDUCTION FOR PATTERN RECOGNITION (B. Chandrasekaran, A. Shapiro) 15

FINITE MEMORY DECISION THEORY (B. Chandrasekaran, C. C. Lam) 15

INTERACTIVE HIERARCHICAL PATTERN GENERATION: THE FACE GENERATION PARADIGM (M. L. Gillenson, B. Chandrasekaran) 16

A NEW BINARY CODE AND ASSOCIATED CELLULAR AUTOMATA FOR PATTERN RECOGNITION BY PARALLEL COMPUTATION (J. Rothstein, C. F. R. Weiman) 16

THE SYMMETRIC TERNARY NUMBER SYSTEM (J. Rothstein, P. Chan) 17

## VI. INFORMATION PROCESSES IN PHYSICAL, BIOLOGICAL AND SOCIAL SYSTEMS

INFORMATION PROCESSING IN BIOLOGICAL SYSTEMS: VISUAL PSYCHOPHYSICS PROJECT (H. R. BLACKWELL, W. CHIOU) 18

## VII. MATHEMATICAL TECHNIQUES

ALGORITHMS FOR SOLVING NONLINEAR SYSTEMS OF EQUATIONS (L. J. White, D. L. Kalmey) 19

APPROXIMATION BY DISCRETE POSITIVE LINEAR OPERATORS (R. Bojanic, O. Shisha) 19

APPROXIMATION OF CONVEX FUNCTIONS BY CONVEX SPLINES AND CONVEXITY PRESERVING CONTINUOUS LINEAR OPERATORS (R. Bojanic, J. A. Roulier) 20

BANDWIDTH MINIMIZATION AND REDUCIBILITY DECOMPOSITION OF SPARSE MATRICES (D. S. Kerr, P. T. Wang, L. J. White) 21

A UNIFIED THEORY OF REGULARLY VARYING SEQUENCES (R. Bojanic, E. Senta) 22

VIII SYSTEM PROGRAMMING


COMPUTER GRAPHICS (C. H. Kearns) 22

CRYPTOGRAPHY AND SECURITY STRUCTURES (W. Griffith, R. Mathis) 23

DEBUGGING - POST MORTEM ANALYSIS (R. Mathis, B. Kirsch, D. Kirschen, R. Atwell, C. Hasbrouck) 23

GRAPHICAL MODEL OF FUNCTIONAL DEPENDENCIES IN A RELATIONAL DATA BASE (D. S. Kerr, D. K. Hsiao) 24

AN INTERACTIVE SYSTEM FOR AUTOMATIC PROGRAM SYNTHESIS (A. W. Biermann, R. BAum, R. Krishnaswamy, F. E. Petry) 24

LOCAL COMPUTER NETWORK (D. K. Hsiao, T. Wyrick) 24

MODELLING OF DATA SECURE SYSTEMS (D. K. Hsiao, E. J. McCauley) 25

PARALLELISM IN COMPUTER PROGRAMS (C. R. Foulk, (. C. Juelich) 25

THE PL/X COMPILER (D. K. Hsiao, H. Su, E. W. Leggett, et. al.) 26

PROGRAM OPTIMIZATION FOR VIRTUAL MEMORY (C. R. Foulk, H. Y. Su) 26

A SMOOTHNESS INDEX FOR COMPUTER FLOWGRAPHS (C. R. Foulk, O. Lange) 26

THEORETICAL FOUNDATIONS FOR CONTEXT PROTECTION AND CONSISTENT CONTROL IN DATA SECURE SYSTEMS (D. K. Hsiao, C. J. Nee) 27


IX. JOINT PROGRAMS


A MANAGEMENT GAME FOR IMPROVING INFORMATION RETRIEVAL SYSTEM MANAGEMENT DECISION-MAKING (F. J. Lazorick, M. J. Lee) 28

SOCIOLOGICAL RESEARCH (L. W. Stern, C. S. Craig, A. J. LaGreca, R. G. Salem) 28


APPENDIXES


A COMPUTER AND INFORMATION SCIENCE COURSE LISTING BY NUMBER AND TITLE 30

B COMPUTER AND INFORMATION SCIENCE FACULTY 33

C COMPUTER AND INFORMATION SCIENCE RESEARCH CENTER SENIOR PERSONNEL 37

D COMPUTER AND INFORMATION SCIENCE SEMINAR SERIES 38

E RELATED ACTIVITIES OF THE STAFF OF COMPUTER AND INFORMATION SCIENCE RESEARCH CENTER 41

F PUBLICATIONS OF THE COMPUTER AND INFORMATION SCIENCE RESEARCH CENTER STAFF 48

G TECHNICAL REPORT SERIES 51

INDEXES

INVESTIGATOR INDEX 56

SUBJECT INDEX 57

# I. THE OHIO STATE UNIVERSITY COMPUTER AND INFORMATION SCIENCE RESEARCH CENTER

## ORGANIZATIONAL STRUCTURE

The Computer and Information Science Research Center at The Ohio State University is an interdisciplinary activity involving the faculty, staff and graduate students from the Department of Computer and Information Science and many other departments dealing with specific applications of computer and information science within the University. The Center also interacts closely with Battelle Memorial Institute and Chemical Abstracts Service, which are adjacent to the Ohio State Campus, as well as with a number of other organizations located in Columbus, Ohio which are engaged in computer and information science research activities, such as Bell Laboratories, Western Electric Corporation, and North American Rockwell Corporation. Although the Research Center and the Department utilize many of the same personnel and have the same Director, they are two separate and distinct entities.

## OBJECTIVES OF THE CENTER

The Computer and Information Science Research Center was established with the support of the National Science Foundation for the following purposes: (1) to develop a broad research program in computer and information science; (2) to develop, test, and evaluate practical applications of research in computer and information science; (3) to coordinate and integrate these functions with an academic program in computer and information science at The Ohio State University, as well as of other disciplines at the University. The Center is also a focal point for a number of applied information processing activities on the campus.

## SCOPE OF THE PROGRAM

The program in computer and information science at The Ohio State University has been defined broadly to encompass most of the analytical activities frequently considered to be part of this discipline. This approach has been chosen because it is felt that in order to generate the needed concepts, foundations, and generalized techniques, it is necessary to examine analytically a number of different areas of computer and information science. In this way a firm empirical and theoretical foundation may be established for generalized information systems. Such a view commits the program not only to the study of information systems, but also to the study of their realization and their impact on the user.

Those areas of study which are emphasized both in the academic program and in the research activities of the Center are as follows:

1. General theory of information
2. Information storage and retrieval
3. Theory of automata, finite state machines, and computability
4. Artificial intelligence, self-organizing and adaptive systems
5. Pattern recognition
6. Computer programming, including systems programming
7. Theory, design, and application of artificial programming languages and translators
8. Digital computer organization and functional design
9. Numerical analysis and mathematical programming
10. Man-machine interaction and systems, particularly in a conceptual sense
11. Computational and mechanical linguistics, semantic analysis, machine translation of natural languages
12. Management information, including logistic information systems, theory of organization, information as a resource
13. Information processing, transmission, and communication in biological systems
14. Social, economic, and psychological aspects of information production, processing, and use.

## FACILITIES

The Computer and Information Science Research Center has a Digital Equipment Corporation DEC System - 10 computer which was obtained with the assistance of a grant from the Office of Computing Activities of the National Science Foundation. This computer is a moderate size flexible time-sharing computer which is dedicated to research and education in the field of computer and information science. This computer provides valuable hands-on experience for the faculty and students of the Computer and Information Science Research Center and permits research activities involving non-standard and innovative applications of computers of both a hardware and software nature. Some of these research activities which are currently underway are:

1) Experimental and developmental research in time-sharing and multiprogramming systems.
2) Complex systems simulation research using graphical display devices.

3) On-line information retrieval systems studies.
4) Hardware modification and interface studies.
5) Software modification and development (e.g., PL/1 and COBOL compilers).
6) Man-machine interaction and psychophysical experiments.
7) Pattern recognition studies.
8) Computer simulation of language learning.
9) Speech analysis and synthesis.
10) Analysis and synthesis of human locomotion.

The Research Center also has access to the University Computer Centers. They are: Instruction and Research Computer Center; Public Service Computer Center; and, University Systems Computer Center.

Included in these centers are an IBM 370/165, an IBM 370/155, and an IBM 370/145 as well as several IBM 1130 machines, and a number of remote terminals.

Many specialized facilities and laboratories of the University are also available to the staff and students of the Research Center. Some of these are the Office of Computer Assisted Instruction, the Institute for Research in Vision, Telecommunications Center, Behavioral Science Laboratory, Listening Center, Communications and Control Systems Laboratory, Mershon Center for Education in National Security, and many others.

The Research Center also interacts with the Ohio College Library Center which is administratively independent of the University. The Center was formed by the Ohio College Association, and operates a common computerized library network connecting the Ohio colleges. (The Ohio College Association consists of most of the colleges and universities in Ohio, both private and state assisted.) Two well established national information systems have units on the campus of The Ohio State University. The MEDLINE system is an automated on-line service to access medical journals of the previous three year period. The ERIC (Educational Research Information Center) system is an automated batch system to access research reports and journal literature in the field of education. These systems are available to the staff and students. Interaction has also been initiated with The Academy for Contemporary Problems, a new organization formed jointly by The Ohio State University and Battelle Laboratories, Columbus.

The University has established a university-centered-information system. The information system, called the Mechanized Information Center (MIC) operates as a department of the University Libraries. MIC is developing a multi-disciplinary batch-mode information system from machine-readable data bases primarily for the campus scientific community. The interface to the MIC system is decentralized as much as possible through the existing system of twenty-three libraries around the campus which serve specialized publics. MIC acquires data bases from commercial sources, as well as from professional societies and governmental agencies. Research activities in MIC are directed toward improving the services of MIC to its users through software refinement and development. This center works closely with the staff and students of the Department and the Center. The director of the MIC is a staff member of the Department of Computer and Information Science and is also a part of the Research Center.

## ACADEMIC PROGRAMS IN COMPUTER AND INFORMATION SCIENCE

The program at The Ohio State University emphasizes education, research, and the professional practice and application of computer and information science. The department offers undergraduate and graduate degrees through the Ph.D. Statistics showing the growth of the department are found in Table 1.

### Organization of The Department of Computer and Information Science

The Department of Computer and Information Science is a separate academic unit located administratively in the College of Engineering, operating in part as an interdisciplinary program with the cooperation of many other departments and colleges throughout the University.

### Objectives of The Department

The program at The Ohio State University emphasizes education, research, and the professional practice and application of computer and information science. The educational program offers undergraduate and graduate degrees through the Ph. D. The research activities which are a central part of the program consist of a broad conceptual base supported by a number of contracts and grants as well as by the university. The broad core research program and these other research tasks interact to form an integrated framework.

### Undergraduate Programs

Undergraduate degrees in computer and information science are available to students in the College of Mathematics and Physical Sciences of the Colleges of Arts and Sciences, to students in the College of Engineering, and to students in the College of Administrative Science. In all there are four different programs and the particular one chosen depends on the student's interests and career objectives.

The undergraduate program in the College of Engineering leads to the degree Bachelor of Science in Computer and Information Science. It is designed for the student who is interested in obtaining both an education in engineering and science, including recommended courses in biology, chemistry, electrical engineering, industrial engineering, physics and psychology.

The undergraduate program in the College of Mathematics and Physical Sciences leads to the degree Bachelor of Science with a major in computer and information science, or to the degree Bachelor of Arts with a major in computer and information science. The degree Bachelor of Science is designed for the student who is primarily interested in obtaining an education in computer and information science and mathematics. The degree Bachelor of Arts is designed for the student who is interested in obtaining both an education in computer and information science and mathematics and an education in some field related to computer and information science.

The undergraduate program in the College of Administrative Sciences leads to the degree Bachelor of Science in Business Administration with a

Table 1: Growth of Department of Computer and Information Science

| | SEPT'67 | SEPT'68 | SEPT'69 | SEPT'70 | SEPT'71 | SEPT'72 | SEPT'73 |
|---|---|---|---|---|---|---|---|
| A. Staff | | | | | | | |
| 1. Full Time | 5 | 11 | 14 | 15 | 18 | 18 | 18 |
| 2. Part Time | 5 | 9 | 10 | 11 | 12 | 14 | 16 |
| B. Graduate Students | 32 | 89 | 114 | 151 | 165 | 187 | 209 |
| C. Undergraduate Students | 100 | 143 | 300 | 485 | 576 | 450 | 510 |
| D. Course Enrollment (Autumn Quarter) | 542 | 770 | 1059 | 1293 | 1447 | 1676 | 1905 (est) |
| | '67-'68 | '68-'69 | '69-'70 | '70-'71 | '71-'72 | '72-'73 | '73-'74 |
| Students Taught | 1977 | 2892 | 3933 | 4703 | 5174 | 5600 | 5950 (est) |
| M.S. Degrees Awarded | 7 | 17 | 35 | 44 | 47 | 49 | 51 (est) |
| Ph.D. Degrees Awarded | | | | | 4 | 8 | 12 (est) |
| Applications for Graduate Study | 181 | 190 | 343 | 425 | 400 | 323 | |
| Graduate Students Associated with Center Totals | 27 | 72 | 78 | 88 | 89 | 83 | |

major in computer and information science. It is designed for the student who is interested in obtaining an education both in computer and information science and mathematics and a general education in the administrative sciences, including courses in accounting, business organization, economics, and geography.

Graduate Programs

The Department of Computer and Information Science offers graduate programs leading to both the Master's and Ph.D. degrees. The graduate program leading to the Master's Degree is available in seven options.

Option I is designed for the student desiring a theoretical foundation in computer and information science.

Option II is designed for the student specializing in information systems.

Option III is designed for the student specializing in computer systems.

Option IV is designed for the student specializing in numerical analysis.

Option V is designed for the student specializing in operations research.

Option VI is designed for the student specializing in biomedical information processing.

Option VII is designed for the student specializing in administrative science.

Each of these options provides a background in several aspects of computer and information science, as well as additional mathematical sophistication appropriate to the student's interest. Each of the options may lead to the Doctoral program in computer and information science, and each may be taken with a thesis option or without a thesis option. (See Appendix A for a listing of courses by number and title.)

All courses of study at the Master's level require completion of a core program in computer and information science, together with the required courses specified for one of the options and additional courses as specified by the student's adviser. The core program includes courses on Introduction to Computer and Information Science, Digital Computer Programming, Digital Computer Organization, Introduction to Linguistic Analysis, Modern Methods of Information Storage and Retrieval, Numerical Analysis, and Introduction to Man-Machine Interaction.

The graduate program leading to the Doctoral Degree in Computer and Information Science is flexible in that it is tailored to the particular background and interests of the individual student. These interests may lie in any one of the research and instructional areas already described as well as

in many other areas resulting from research and instructional programs jointly undertaken withother departments. Only students who have demonstrated outstanding scholastic ability in their beginning graduate work will be admitted to the academic and research program leading to the doctorate.

Course Offerings

Currently there are about 77 courses (each one quarter in length) offered by the Department, 20 of which are largely undergraduate with the remainder being upper level undergraduate and graduate courses. In addition to these courses there are over two hundred courses offered by a variety of departments of the University which are of interest to our graduate students who are encouraged to take these courses.

Faculty

The Department of Computer and Information Science has a full time faculty of sixteen members at the assistant professor level and above. They have a wide range of backgrounds and experience. The above faculty is supplemented by staff who have joint appointments with other departments; by staff from other departments who teach courses primarily for Computer and Information Science students; and by staff people who are employed at Battelle Memorial Institute, Chemical Abstracts Service, and Bell Laboratories who teach courses in the Department of Computer and Information Science (see Appendix B). There are currently a total of about 18 supplemental staff in this category.

INTERACTION WITHIN THE UNIVERSITY

Both the Research Center and the Department of Computer and Information Science interact with other departments and research programs within the University. This is essential because of the multi-disciplinary nature of the activities encompassed in this field. A number of the academic faculty have joint appointments in other departments. Staff members of the Department of Computer and Information Science have appointments in the following departments and organizations:

a. Mathematics
b. Linguistics
c. Psychology
d. Biophysics
e. Electrical Engineering
f. Accounting
g. Engineering Graphics
h. Instruction and Research Computer Center
i. University Systems Computer Center
j. University Libraries
k. Mechanized Information Center

Participating in the activities of the Computer and Information Science Research Center are representatives of the following departments:

a. Computer and Information Science
b. Mathematics
c. Linguistics
d. Biophysics
e. Electrical Engineering

Names of the principal investigators for various research activities and the senior staff positions are included as Appendix C.

## INTERACTION WITHIN THE INFORMATION SCIENCE COMMUNITY

Columbus, Ohio is one of the major centers for information science and for the transfer of information in the United States. A number of organizations are involved with the activities of computer and information science. This affords an opportunity for students and faculty to interact with appropriate personnel in these organizations. Some of these are:

a. Chemical Abstracts Service
b. Batelle Memorial Institute
c. Bell Laboratories
d. Western Electric Corporation
e. North American Rockwell Corporation
f. Industrial Nucleonics
g. State of Ohio Department of Finance; Department of Highways
h. Highlights for Children
i. Columbus Board of Education

There are a large number of scientists who come to Columbus in order to visit with the Department and Center and who usually present a seminar. (The seminars for the period of this report are listed in Appendix D.) The people cover virtually all phases of computer and information science.

In addition, our people interact at most of the major technical meetings in this country as participants giving papers, assisting on panels, as attendees, and as officials. Hardly a major technical meeting in the appropriate fields is held without a contribution from one or more of the personnel from the Ohio State Computer and Information Science Research Center. A list of these activities can be found in Appendix E.

Research efforts of the staff are disseminated to the professional community through several publication channels. A list of current publications of the Research Center staff is included as Appendix F. In addition, the Research Center issues a technical report series ( see page 9).

## DOCTOR OF PHILOSOPHY DEGREE

One of the results of the interdisciplinary research activity of the computer and Information Science Research Center has been the awarding of the Ph.D. degree to the following personnel this past year.

| Name | Title | Department | Date of Degree |
|---|---|---|---|
| Wun-chun Chiou | Toward a Complete Theory of Spatial Organization of the Human Visual System at Impulse Detection Threshold | Biophysics | 1973 |
| Thomas A. DeFanti | The Graphics Symbiosis System- an Interactive Mini-Computer Animation Graphics Language Designed for Habitability and Extensibility | Computer and Information Science | 1973 |
| David H. Gelperin | Clause Deletion in Resolution Theorem Proving | Computer and Information Science | 1973 |

| | | | |
|---|---|---|---|
| David R. Harris | GOLDA: A Graphical On-Line System for Data Analysis | Computer and Information Science | 1972 |
| John C. Klippert | Necessary and Sufficient Conditions for the Uniform Convergence of Interpolating Polynomials to Functions in $C_T^*(\omega)$ | Mathematics | 1972 |
| W. Michael Lay | The Double-KWIC Coordinate Indexing Technique: Theory, Design, and Implementation | Computer and Information Science | 1973 |
| You-Hwa Lee | Asymptotic Properties of Convolution Products of Sequences | Mathematics | 1973 |
| Betty Ann Mathis | Techniques for the Evaluation and Improvement of Computer-Produced Abstracts | Computer and Information Science | 1972 |
| Carl F.R. Weiman | Pattern Recognition by Retina-Like Devices | Computer and Information Science | 1972 |
| Bruce J. Whittemore | A Generalized Decision Model for the Analysis of Information | Computer and Information Science | 1972 |
| Carol E. Young | Development and Language Analysis Procedures with Application to Automatic Indexing | Computer and Information Science | 1973 |

RECENT TECHNICAL REPORTS

The Computer and Information Science Research Center began publishing a technical report series in 1968. Since that time a total of seventy-three technical reports have been issued. A list of recent reports (see Appendix G for complete list) of the research center follows.

CHANDRASEKARAN, B.; REEKER, L. H. Artificial intelligence - a case for agnosticism. August, 1972. 28p. (OSU-CISRC-TR-72-9)

FOULK, C. R.; JUELICH, O. C. Smooth programs and languages. November, 1972. 17p. (OSU-CISRC-TR-72-13)

HSIAO, D. K.;DENICOFF, M.; BERGART, J. G. An annotated and cross-referenced bibliography on computer security and access control in computer systems. November, 1972. 59p. (OSU-CISRC-TR-72-12)

LAY, W. M. The double KWIC coordinate indexing technique: theory, design, and implementation. February, 1973. 250p. (OSU-CISRC-TR-73-1)

MATHIS, B. A. Techniques for the evaluation and improvement of computer-produced abstracts. December 1972 262p. (OSU-CISRC-TR-72-15)

ROTHSTEIN, J. Loschmidts's and Zermelo's paradoxes do not exist. October, 1972. 9p. (OSU-CISRC-TR-72-10)

STRONG, S. M. An algorithm for generating structual surrogates of English text April 1973. 140p. (OSU-CISRC-TR-73-3)

WEIMAN, C. F. R.; ROTHSTEIN, J. Pattern recognition by retina-like devices. July, 1972. 154p. (OSU-CISRC-TR-72-8) (PB-211 238)

YOUNG, C. E. Development of language analysis procedures with application to automatic indexing. April 1973. 298p. (OSU-CISRC-TR-73-2)

YOVITS, M. C.; CHANDRASEKARAN, B. Artificial intelligence. December. 1972. 39p. (OSU-CISRC-TR-72-11)

YOVITS, M. C.; WHITTEMORE, B. A generalized conceptual development for the analysis and flow of information. December 1972. 31p. (OSU-CISRC-TR-72-14)

## II. INFORMATION STORAGE AND RETRIEVAL

### AUTOMATIC INDEXING

The theory, design, and implementation of the Double-KWIC (D-KWIC) Coordinate Indexing Technique is the topic of a recent Ph. D. Thesis by W. Michael Lay. The thesis describes in detail the motivation for and development of the initial prototype model for this new automatic technique followed by the subsequent evolutionary changes in the model to improve both the efficiency of the technique and the quality of the indexes produced by the technique. These evolutionary changes include (1) introduction of some automated vocabulary control features to eliminate scattering caused by singular and plural main terms; (2) replacement of the prototype D-KWIC indexing system by a KWOC-D-KWIC hybrid system to reduce the size and improve the quality of the indexes produced; (3) subsequent introduction of a KWIC-D-KWIC hybrid system to automate the main term selection process which previously required a human interface step in each of the earlier systems.

The programs for implementing the KWOC-D-Kwic and KWIC-D-KWIC index generating systems (with or without automated vocabulary control) are described in Lay's thesis together with information on how to use them. The Thesis also includes a KWIC-D-KWIC index of the topics discussed therein based on entries in the table of contents and the list of figures.

Future research in this area will be directed towards additional algorithmic methods of vocabulary control and cross-referencing, in additional to development of an absolute measure of scattering to permit quantitative measurement of the extent to which scattering is eliminated by various types of vocabulary control.

(A. E. Petrarca, W. M. Lay, W. S. Stalcup)

### A SEQUENTIAL-ANALYSIS CLASSIFICATION TECHNIQUE

This research involves both the study of a sequential-analytic technique for automatically classifying documents and the concurrent development of objective criteria with which to evaluate automatic classification procedures. The primary advantage of the sequential-analytic technique is that the entirety of each document need not be scanned before the document is classified, thus resulting in increased efficiency. Research is needed to determine appropriate sample procedures, as well as characterization of the resultant categories. Another advantage of the technique is the flexibility produced by the numerous parameters which can be externally controlled and specified. The second goal of this research is to develop evaluation criteria for automatic document classification prodedures in general, and the sequential-analytic technique in particular. These criteria should include computational complexity, storage requirements, and stability. The stability of a classification procedure provides an indication of its sensitivity to error or to the addition of one more key term or document to be classified. For the sequential-analytic technique, it is also desired to obtain a measure of the truncation error caused by not reading all the terms in a document.

(J. E. Rush, L. J. White)

## III. HUMAN INFORMATION PROCESSING

### TRANSFER PROCESSES IN MEMORY

This project is concerned with the investigation of transfer mechanisms and properties of the transfer mechanisms among subsystems of human memory. The major emphasis to date has been on the interaction of very-short-term memory with more permanent subsystems. During the past year, the use of probabilistic automata as models of human behavior have been investigated. A model fitting the data quite well was developed. From it, inferences were made regarding the order and rate of items transferred from very-short-term memory to other subsystems.

(R.L. Ernst, S. Hepler)

# IV. INFORMATION ANALYSIS

## A GENERAL THEORY OF INFORMATION FLOW AND ANALYSIS

A generalized framework for the development of a theory of information flow which permits the analysis and quantification of information has been suggested. In addition to its theoretical and conceptual interest, there are major and immediate implications for the development of information systems and networks as well as for the general understanding of information flow, retrieval, and transfer.

Numerous intuitive notions exist about the interrelationship between information and decision-making. At the pragmatic level, information has value to the extent that it is useful as a resource for purposeful activity. The primary "purposeful activity" in life is decision-making. Hence, information and decision making are inextricably tied together. In our formulation in fact, information is defined in just that way as being data of value of decision making.

As a consequence, a measure of the amount of information in a data set or message is defined in terms of a quantity called the decision state of a decision-maker. The decision state is a function of the determinism of the decision-maker. We suggest a way of evaluating the decision state quantitatively in terms of a specific, but only illustrative, decision rule. We assume that the decision-maker will tend to select that alternative whose outcome yields the maximum expected relative value to the decision-maker.

Thus, we define probabilities of choice for each alternative available that are proportional to the expected value of that alternative. We suggest that these probabilities of choice will define the decision state of the decision-maker. In evaluating the decision state we use functions of these probabilities of choice which reflect the determinism of the decision-maker. There are a number of possible functions that could be used.

One measure that is especially appealing is a measure suggested by Ackoff that indicates a distance from indeterminism:

$$\sum_{i=1}^{m} \left| P(a_i) - \frac{1}{m} \right|$$

using this measure the value of the decision state is then

$$V(DS) = \frac{\sum_{i=1}^{m} \left| P(a_i) - \frac{1}{m} \right|}{2 - \frac{2}{m}}$$

The pragmatic information I contained in a set of data D can be defined by the impact of this data on the value of the decision-maker's decision state at times t and t + 1.

$$I(D) = V(DS_{t+1}) - V(DS_t) \quad .$$

Stated in words, the measure of pragmatic information in a data set or message is equal to the difference of the value of the decision state of the decision-maker after and before receipt of the message.

The decision state has been defined so that it reflects the decision-maker's understanding of a particular decision situation at a particular point in time. Consequently, I(D), the pragmatic information content of data set D, is a situation dependent and time dependent measure. The data acquired, processed, stored, and disseminated by information systems will be used, however, as a resource by many different decision-makers at various points in time. Hence, there is a need for quantifying the information contained in a data set in terms of its overall usefulness for a range of decision-makers over a period of time.

Clearly, the information content of a data set is strongly dependent on the particular decision-maker using this resource. Since decision-makers vary with regard to their effectiveness in a given situation, it is reasonable to consider ranking decision-makers according to their "effectiveness". The information measure which we have defined can then be expressed as a function of the decision-maker-effectiveness. Since what is really desired is some indication of the average value of this data set for the decision-maker over a period of time, one can determine some index $\overline{I(D)}$ of the average information contained in a data set D over a period of time. If one then assesses the effectiveness of each of the decision-makers for whom this data set serves as a resource, an information profile for data set D can be formulated by determining $\overline{I(D)}$ for each decision-maker. Thus, we may establish an information profile for any data set or document, which is defined as the functional relationship between information content and decision-maker-effectiveness. Such an information profile indicates the composite information content of a data set for a spectrum of decision-makers. Methods, procedures, and analyses for establishing these profiles are being studied.

(M. C. Yovits, J. G. Abilock)

# V. ARTIFICIAL INTELLIGENCE

## AUTOMATIC THEOREM PROVING

This research has been concluded with the completion of the Ph. D. dissertation by D. Gelperin. The new elimination principles based on the so called E-representation and I-representations developed during the course of this research have been extensively investigated and the conditions under which their use is cost-effective in automatic theorem proving have been identified.

(B. Chandrasekaran, D. Gelperin)

## DECISION THEORY FOR PATTERN RECOGNITION

If $p(x)$ and $q(x)$ are the densities for the N-dimensional measurement vector x, conditioned on the classes $c_1$ and $c_2$, and if finite sets of samples from the two classes are available, then a decision function based on estimates $\hat{p}(x)$ and $\hat{q}(x)$ can be used to classify future observations. In general, however, when the measurement complexity (the dimensionality N) is increased arbitrarily and the sets of training samples remain finite, a "peaking phenomenon" of the following kind is observed: classification accuracy improves at first, peaks at a finite value of N, called optional measurement complexity, and starts deteriorating thereafter. We have been investigating the problem when the measurements are statistically independent. The following is a summary of our major new results.

1. If the measurements are quantized, say to k levels each, then, in general, finite sample sets and dimensionality, there is an optional quantization complexity, $k_{opt}$ which increases with the sample size for fixed N and decreases with N for fixed sample size. These results are of heuristic importance in classification of images by means of quantized measurements made on the images.

2. We have derived general conditions which can be used to decide whether N can be increased without the occurrence of the peaking phenomenon. These compact conditions can be applied to a variety of cases without the need for starting from first principles every time, including cases which were previously intractable.

3. By applying the above conditions, we can show some rather surprising, not to say counter-intuitive, results. The general thrust of these results is that independence alone does not quarantee the absence of the peaking phenomenon. Specifically:

a. In the case of discrete measurements, the use of maximum likelihood estimates generally results in a finite optimal measurement complexity; the only case where the optimal measurement complexity is guaranteed to be infinite is where Bayesian estimates based on assumed a priori's are employed, and even then only for the average performance over all problems generated by the assumed a priori's. Among this set of problems, there exist many for which the optimal measurement complexity is again finite.

b. In the case of continuous measurements, when one uses maximum likelihood estimate-based decision functions, sometimes unequal number of samples from the two classes can cause the optimal measurement complexity to become finite, while throwing away the excess samples from the class with larger representation restores monotonically increasing performance.

4. We have obtained bounds on the classification error as a function of distance functions for the finite sample case for independent measurements. All previous results on error probability and distance functions have been concerned with known densities.

(B. Chandrasekaran, A. K. Jain)

DIMENSIONALITY REDUCTION FOR PATTERN RECOGNITION

In previous reports, we have discussed the use of the so-called space-filling curves as one of the tools in a clustering package. We have conducted extensive computer experiments in which various two dimensional clusters were mapped on the real-line by means of these curves, and the cluster-preserving ability of this technique was studied. The results were sufficiently promising, and as a result we are now writing a program which maps clusters in a higher dimensional space to the real-line. We expect that this technique may not be reliable enough to be used as the sole clustering technique, but as one tool to be used in conjunction with other techniques in a clustering package, it might have promise.

(B. Chandrasekaran, A. Shapiro)

FINITE MEMORY DECISION THEORY

We have obtained a class of deterministic finite memory algorithms which are the best, in terms of error probability, among known deterministic algorithms for the symmetric hypotheses testing problem. There are strong reasons to believe that the optimal algorithm is a member of this class.

(B. Chandrasekaran, C. C. Lam)

## INTERACTIVE HIERARCHICAL PATTERN GENERATION: THE FACE GENERATION PARADIGM

This work is concerned with applying the concepts of artificial intelligence to the generation of a complex pattern on a graphic display. The chosen pattern is the human face, which is highly variable and yet can be easily broken down into sub-features.

Experiments were conducted in an attempt to determine usable facts concerning the correlations of the sizes of facial features. Other experiments included work with caricatures in an attempt to determine the relative importance of facial features in recognition.

From these experiments and the results of the work of others, a heuristic strategy was developed which will allow a non-artist to create on the scope a line drawing of a face which he has in front of him on a photograph. The strategy includes the concepts of always working in the context of a complete face, achieving at an early stage the correct outline of the face, and the ability to hierarchically manipulate the features.

The strategy is being implemented on a PDP 11/45, Vector General Scope hardware system, using the Graphics Symbiosis System of the Computer Graphics Research Group as the software base.

(M. L. Gillenson, B. Chandrasekaran)

## A NEW BINARY CODE AND ASSOCIATED CELLULAR AUTOMATA FOR PATTERN RECOGNITION BY PARALLEL COMPUTATION

In pattern recognition, geometric transformations (rotation, etc.) require computations whose execution times increase rapidly with increasing grid resolution. A code for straight lines embodying such transformations in locally applied, parallel-executable algorithms has been found. Some properties: (1) Code digits are determined by nearest-neighbor configurations of grid cells crossed by the line. (2) For all slopes, codes on nxn grids are n digits long. (3) Rational slopes on the infinite grid correspond to periodic codes and conversely. (4) Translation and rotation of lines results in cyclic shifts in certain substrings of their codes. (5) There is a 1-to-1 correspondence between distinquishable n-digit line codes and the Farey series of order n. (6) Certain perspective transformations correspond to the rewriting of code substrings as single digits.

Property (6) leads to recognition algorithms reducing codes of straight lines to a single digit, rejecting other code strings. The algorithms are simultaneously applicable to entire strings. They have been used to design cellular automata recognizing straight lines. With simple modifications the automata construct polygonal approximations of curves and recognize topological connectivity. The logical designs are independent of line slope or position or grid size.

Each step in the recognition algorithm corresponds to a step in the continued fraction development of the slope of the line. Thus, the operations of the line recognizing cellular automaton may be viewed as parallel computations on numbers (slopes) in a base-free binary notation. It can be shown from the continued fraction structure of the code that truncating the infinite (aperiodic) code of a line of irrations slope by projecting it onto a finite grid yields the code of the best rational approximation to that number for the grid size. This and other properties of the code and associated cellular automata suggest applications not only to pattern recognition but to truly parallel numerical computation.

Property (4) expresses invariance of homogeneity in digit distribution under geometric transformations of the line. It has been used to design another cellular automaton in which the timing and spacing of changes in the configuration of cells crossed by the line during translation leads to recognition. Translation changes the roles of grid cells, inducing code changes. To preserve homogeneity, these changes must be uniformly spaced. They constitute a cyclic shift of fixed magnitude in the code which is repeated as the line is moved. Only straight line codes have this property. This example, where relative motion of pattern and grid is useful in pattern recognition suggests the possiblity that eye tremor may be important in visual perception or recognition of patterns.

It has been proved that the set of periods of rational slopes, interpreted as a formal language over the alphabet {0,1}, constitute a context-sensitive languages. A generative grammar has been constructed for it, also a linear bounded automaton to recognize it.

(J. Rothstein, C. F. R. Weiman)

## THE SYMMETRIC TERNARY NUMBER SYSTEM

The symmetric ternary number system, whose digits are 0, 1, and -1 has been extensively studied, as have its implications for arithmetic algorithms and for computer system design. Substantial savings in computer time and reductions in algorithmic and circuit complexity appear to be achievable by using it.

Among the reasons for the advantageous nature of this number system are:

(1) uniform representation of positive and negative numbers making the sign bit unnecessary
(2) change of sign is trivially simple, making addition and subtraction only trivially different
(3) the most significant digit carries the sign of the numbers
(4) truncated numbers are rounded off without performing any further operations on them
(5) errors are unbiassed
(6) because of digit cancellation carry chains are tremendously reduced in average length

(7) all advantages of optimality of base 3 are retained
(8) coding of groups of multiplies digits for increased speed of multiplication is easily implemented
(9) parallel multiplication, as well as division, are particularly advantageous in symmetric terrary
(10) many speed-up schemes devised for binary turn out to be part of the symmetric ternary algorithms without additional special arrangements.

(J. Rothstein, P. Chan)

## VI. INFORMATION PROCESSES IN PHYSICAL, BIOLOGICAL AND SOCIAL SYSTEMS

### INFORMATION PROCESSING IN BIOLOGICAL SYSTEMS: VISUAL PSYCHOPHYSICS PROJECT

This project is concerned with development of a general theoretical model for the spatial organization of the human visual system. Important progress was made during 1972-73, made possible by the refinements in the computer program described last year. Analysis of all relevant detection threshold data collected since 1948 reveals that theoretical predictions now agree within acceptable limits with all experimental data for noncircular targets provided the theory have the following components: (a) linear summation based upon the point spread function (PSF) derived from circular targets; (b) a threshold for linear summation in unusual cases in which target elements contributing little to the figure spread function (FSF) were also reduced in luminance compared with other target elements; (c) partial as well as complete multiple-site probability summation; and (d) a reduced grain in the FSF in a latter stage of information processing.

The present statement of the theory refers only to average values across time. We are hoping to expand the theory to cover the probabilistic nature of momentary states. In the process, we hope to collapse theoretical components (c) and (d) described above into a single theoretical component.

(H. R. Blackwell, W. Chiou)

## VII. MATHEMATICAL TECHNIQUES

### ALGORITHMS FOR SOLVING NONLINEAR SYSTEMS OF EQUATIONS

The success of algorithms for solving nonlinear systems of equations is very dependent on the nature of the particular system being solved as well as the initial approximation to the solution. Often a specialized technique which takes into account the nature of the given system will be develcped solely for the solution of that problem. However, it would be preferable to avoid doing the latter and instead be able to use certain characteristics of the given system to ascertain which algorithm is best suited for solving the given problem.

The purpose of this research is to develop a set of parameters depicting the nature of a given nonlinear system and to use these parameters in developing an automatic procedure for selecting the most effective routine for attempting to solve the given nonlinear system. Implicit in this work is the extensive testing of several existing routines for solving nonlinear systems. Production routines instead of algorithms are tested since the results of a given algorithm are dependent on its particular implementation. Hopefully this will not only give insight into establishing those parameters of a given nonlinear system that are numerically significant, but also establish the domain of robustness of these routines.

(D. S. Kerr, L. J. White, D. L. Kalmey)

## APPROXIMATION BY DISCRETE POSITIVE LINEAR OPERATORS

The following is a known result:

Theorem A. For $n = 1,2,\ldots$, let $\phi_n$ be a $2\pi$-periodic, continuous, even and non-negative function, with the Fourier series $\frac{1}{2} + \sum_{k=1}^{\infty} \rho_{k,n} \cos kx$,

Then for every continuous, $2\pi$-periodic function f, we have

$$\max_{-\infty<x<\infty} | L_n(f,x) - f(x) | \leq (1+\pi)\, \omega\left(f, \sqrt{\frac{1-\rho_{1,n}}{2}}\right)$$

where

$$(*) \qquad L_n(f,x) = \frac{1}{\pi} \int_0^{2\pi} f(t)\, \phi_n(t-x)\, dt, \quad n = 1,2,\ldots$$

If $\phi_n$ is a trigonometric polynomial, then $L_n(f,.)$ is also a trigonometric polynomial whose coefficients can be expressed in terms of the Fourier coefficients of f. Although the degree of approximation by trigonometric polynomials of this type can be very close to the optimal, the effective construction of these polynomials requires numerical evaluation of integrals, which in a certain sense restricts their usefulness from the computational point of view. Since the evaluation of integrals is based on a quadrature formula, it is clear that most useful approximating polynomials from the computational point of view will be obtained if the integral in (*) is replaced by a quadrature formula - type sum, provided this doesn't change essentially the degree of convergence. In this paper the following discrete version of Theorem A is proved:

Theorem B. For $n = 1,2,\ldots$, let $\phi_n$ be a non-negative cosine polynomial

$$\phi_n(x) = \frac{1}{2} + \sum_{k=1}^{m_n} \rho_{k,n} \cos kx. \text{ Then for every continuous, } 2\pi\text{-periodic}$$

function f we have

$$\max_{-\infty<x<\infty} | K_n(f,x) - f(x) | \leq (1+\pi)\, \omega\left(f, \sqrt{\frac{1-\rho_{1,n}}{2}}\right),$$

where

$$K_n(f,x) = \frac{2}{m_n+2} \sum_{k=1}^{M_n+2} f(t_{k,n})\, \phi_n(t_{k,n}-x)$$

and $t_{k,n} = 2k\pi/(m_n+2)$, $k=1,\ldots, m_n+2$, $n=1,2,\ldots$

(R. Bojanic, O. Shisha)

APPROXIMATION OF CONVEX FUNCTIONS BY CONVEX SPLINES AND CONVEXITY PRESERVING CONTINUOUS LINEAR OPERATORS

Let f be a function defined on [a,b]. By $[f(x_0),\ldots,f(x_\ell)]$ we mean the $\ell$th divided difference of f:

$$[f(x_0),\ldots,f(x_\ell)] = \sum_{k=0}^{\ell} f(x_k)/\, w_j'(x_k)$$

where $w_j(x) = (x-x_0)\ldots(x-x_j)$, $j = 0,1,2,\ldots$

The function f is a convex function of order $\ell$ if $[f(x_0),\ldots,f(x_\ell)] \geq 0$ for every choice of $a \leq x_0 < \ldots < x_\ell \leq b$. The set of all continuous, convex functions of order $\ell$ will be denoted by $K_\ell[a,b]$.

Our main result is the following approximation theorem:

THEOREM 1. Every $f \in K_\ell[a,b]$ may be approximated uniformly on [a,b] by spline functions of the form

$$g(x) = \sum_{k=0}^{\ell-1} A_k(x-a)^k + \frac{B}{n} \sum_{i=1}^{n-1} (x-c_i)_+^{\ell-1}$$

where $(x-c)_+^{\ell-1} = (x-c)^{\ell-1}\chi_{[c,b]}(x)$, $B \geq 0$ and $c_i \in (a,b)$, $i=1,\ldots,n-1$.

Results of this type can be used to characterize convexity preserving continuous linear operators. Let C[a,b] be the space of continuous functions on [a,b] and $\Psi : C[a,b] \to C[a,b]$ a continuous linear operator.

THEOREM 2. Let $\ell \geq 2$ and $r \geq 0$. In order that for every $f \in K_\ell[a,b]$ we have $\Psi(f,\cdot) \in K_r[a,b]$ it is necessary and sufficient that

(i) $[\Psi(P,x_0),\ldots,\Psi(P,x_r)] = 0$ for every $a \leq x_0 < \ldots < x_r \leq b$ and every polynomial P of degree $\leq \ell-2$

(ii) $\Psi((t-c)_+^{\ell-1}, \cdot) \in K_r[a,b]$ for every $c \in (a,b)$

THEOREM 3. Let $\ell \geq 2$ and let M[a,b] be a closed convex cone in C[a,b]. In order that for every $f \in \bigcap_{i=1}^{\ell} K_i[a,b]$ we have $\Psi(f,\cdot) \in M[a,b]$ it is necessary and sufficient that

(i) $\Psi((t-a)^r,\cdot) \in M[a,b]$ for every $0 \leq r \leq \ell-1$

(ii) $\Psi((t-c)_+^{\ell-1},\cdot) \in M[a,b]$ for every $c \in (a,b)$

Theorems 2 and 3 are true also if $c=1$ if one assumes that $\Psi((t-c)_+^0,\cdot)$ has a meaning, since the function $(t-c)_+^0 = \chi_{[c,b]}(t)$ is not continuous on $[a,b]$.

Special cases of these results were obtained earlier by T. Popoviciu who has studied monotonicity preserving operators of the form

$$\Psi(f,x) = \sum_{i=1}^{n} f(\xi_i)\,\varphi_i(x)$$

where $a \le \xi_1 < \ldots < \xi_n \le b$ are fixed points in $[a,b]$ and $\varphi_i$, $i = 1,\ldots,n$ are differentiable functions on $[a,b]$. Similar results were obtained by J. Roulier for operators of the form

$$\Psi(f,x) = \int_a^b f(t)K(x,t)\,dt$$

where $K$ is a continuous function on $[a,b]\times[a,b]$.

(R. Bojanic, J. A. Roulier)

## BANDWIDTH MINIMIZATION AND REDUCIBILITY DECOMPOSITION OF SPARSE MATRICES

Algorithms have been developed for bandwidth reduction and reducibility decomposition of sparse matrices. These algorithms determine row and column permutations by examination of the graph representing the nonzero elements of the matrix. A concept of the stability of a bandwidth reduction algorithm has been introduced. An algorithm which squeezes arbitrary sparse matrices into banded form has been constructed and has been shown to be stable, convergent and reasonably fast. An algorithm which separates two strongly connected components in a directed graph with a arcs and n nodes with $O(a)$ tests and $O(n)$ assignments has been developed and has been used to compute all the irreducible constituents of a given sparse matrix. Decomposable matrices, a class more general than reducible, has been defined. It has been shown that the problem of decomposition of sparse matrices by permutation matrices is a well posed problem and that any algorithm which computes the irreducible constituents of a sparse matrix can also be used to compute the nondecomposable constituents.

(D. S. Kerr, P. T. Wang, L. J. White)

## A UNIFIED THEORY OF REGULARLY VARYING SEQUENCES

In analogy to the definition of regularly varying (RV) functions in the sense of Karamata, a sequence of positive terms, $(c(n))$, is said to be RV if. for all $\lambda > 0$,

$$(*) \qquad \lim_{n\to\infty} \frac{c([\lambda n])}{c(n)} = \Psi(\lambda)$$

where $0 < \Psi(\lambda) < \infty$ . This definition has been used by several authors as a starting point for studies involving RV sequences. The underlying theory and properties of such RV sequences is then assumed to be developable in obvious analogy to Karamata's treatment for functions and is omitted. In this paper it is shown that an analogous theory can be developed from (*), but that this development is not generally close, and sometimes far, from a simple imitation of arguments for RV functions.

The main results can be stated as follows:

Theorem 1. For a RV sequence $(c(n))$ the limit function $\Psi$ has the form $\Psi(\lambda) = \lambda^{\rho}$ for some finite $\rho$ and all $\lambda > 0$.

Theorem 2. If $(c(n))$ is a RV sequence, the function $R(x) = c([x])$ is a RV function.

The proofs of these theorems are based on a result which is interesting in itself: If $(c(n))$ is a RV sequence, then $c(n+1)/c(n) \to 1$ $(n \to \infty)$. Once Theorem 2 is proved, the theory of RV functions is used to deduce some of the analogous properties of RV sequences. The following result is typical:

A sequence $(c(n))$ of positive terms is a RV sequence if and only if there exists a real number $\gamma$ and sequences $(\eta(n))$ and $(\delta(n))$ converging to a finite limit and zero, respectively, such that

$$c(n) = n^{\gamma} \exp\left(\eta(n) + \sum_{k=1}^{n} \frac{\delta(k)}{k}\right) \qquad n=1,2,\ldots$$

(R. Bojanic, E. Senta)

## VIII. SYSTEM PROGRAMMING

### COMPUTER GRAPHICS

A principal use of the graphic language is for the precise description of 3-dimensional geometric shapes. Except for elementary forms, for which mathematical formulas exist, computer definition of the shape of objects is difficult. Current research is underway to devise easy-to-use systems for the definition, manipulation, and display of geometric components and the solution of special problems involving relationships between them. Difficulty encountered by engineers and designers in the use of existing systems has hindered application of the computer to engineering design and documentation. A generalized graphics package has been developed. The package employs standard plotting software, graphics terminals, and plotting devices for the computer generation of engineering drawings and diagrams, complete with standard symbols, details and specifications.

(C. H. Kearns)

## CRYPTOGRAPHY AND SECURITY STRUCTURES

Most previous work on cryptography has been related to the security of transmitted messages or stored documents. Computers and cryptography have been related interms of encrypting schemes done easily by computers, safeguarding transmissions to and from terminals, and safeguarding data files from physical theft. These techniques provide some degree of data security, but do not allow usual data processing in the encrypted form.

Our research effort is concerned with identifying those data processing functions which must be done in a secure state and how those relate to the structure of the data. One phase of encrypting is to destroy the original structure. We are studying what structural information must be retained to permit normal data processing functions.

Related to this, we are studying ways to specify these relationships in terms of the security levels desired. This leads to a two level mapping of the data - data structure and security structure. These structures should closely match the relationships already established by the user. In physical storage they will be accomplished by a variety of data structures, pointers, and encrypted records.

(W. Griffith, R. Mathis)

## DEBUGGING - POST MORTEM ANALYSIS

Debugging aids fall in three main categories - real time interaction with running program, execution history to be used after termination, and post mortem debugging aids. The most common post mortem debugging aid is the core dump. This has the minimum overhead since it is only invoked upon abnormal termination of the executing program.

Our research has been in the direction of providing more useful information in the dump - error codes would be more fully explained; control blocks interpreted with certain flags pointed out; sections of code disassembled; possible causes of the error pointed out; fix-ups suggested.

We are also working with other debugging aids in an attempt to develop at total debugging system providing debugging aids in all three categories, of varying levels of complexity and power, and of varying overhead requirements.

(R. Mathis, B. Kirsch, D. Kirschen, R. Atwell, C. Hasbrouck)

GRAPHICAL MODEL OF FUNCTIONAL DEPENDENCIES IN A RELATIONAL DATA BASE

A relational model for data base management systems has been proposed to allow the user to express logical relationships among the data without having to be concerned with design and implementation details such as storage structures. In this model information is represented as sets of relations. Various normal forms of relations have been suggested in order to make the sets of relations easier to understand and control, simpler to operate upon and more informative to the casual user. When there are many relations in a data base, there are many possible choices of normalized relations. It is the purpose of this research to develop a graphical model of the dependencies among different attributes of one or more relations and to use this model to select the best representation of the relation or relations.

(D. S. Kerr, D. K. Hsiao)

AN INTERACTIVE SYSTEM FOR AUTOMATIC PROGRAM SYNTHESIS

A man-machine interactive computer programming system is under development which will enable a person to work through example calculations and which will automatically synthesize a program for doing those calculations. The system will thus enable the user to "show" a computer how to do a calculations rather than having to write a program in the traditional manner. This system, called an autoprogrammer, works by storing the complete sequence of actions executed during an example computation and then systhesizing the smallest computer program which is capable of executing the example. If the program is incorrect, one or two more examples may be added but this is usually not necessary. The typical amount of computer time required to complete a synthesis is less than one minute for small programs.

(A. W. Biermann, R. Baum, R. Krishnaswamy, F. E. Petry)

LOCAL COMPUTER NETWORK

The objective of this study is to propose a system configuration on the interconnection of the IBM 370/165, DEC System-10 and Micro 1600/21 computer systems. The interconnected systems can serve as a basis for the study of computer network and facilitate better utilization of all the computers involved.

A configuration with low cost and adequate performance has been proposed. This configuration calls for an utilization of the Micro 1600 as a communication processor, a synchronous communication interface between the Micro 1600 and IBM 370/165 and an asynchronous communication

interface between the Micro 1600 and DEC System-10. The particular interconnection not only will impact minimally the existing operating systems of the computers involved but also will rely exclusively off-the-shelves hardware components. A cost estimation of the needed hardware components and software development is also included in the proposal.

(D. K. Hsiao, T. Wyrick)

MODELLING OF DATA SECURE SYSTEMS

The goal of the research is to provide a model with which the relevant issues in access control, such as security, integrity, privacy protection and controlled information sharing, can be studied, on the one hand; and the conventional procedures such as identification, authentication, authorization, and compartmentalization can be characterized, on the other hand. A multi-level model is being developed to allow the different problems in data security to be considered at a level of abstraction appropriate to the specific issue and procedure under study. The highest level is conceptual. In it, "patterns of protection" (intuitively, the ways the users may access the data) can be defined in formal and unambiguous ways. The intermediate level of the model is structural. Here, the primitives to be utilized in the realization of the patterns of protection defined in the higher level will be specified. The most important feature of this level is that the critical functions of an access control mechanism are no longer carried out by complex, and thus potentially unreliable, programs, but are inherent in the basic structure of the system by the utilization of deadlocks. When a user attempts an unpermitted access, he deadlocks with a "pseudo-user" and cannot proceed. Thus, the demonstration of system correctness involves the certification of a limited number of small, single-purpose modules and the verification of the correctness of the user/pseudo-user interaction. On the lowest level, a system to illustrate the utility and practicality of the model will be created. Overall, the research should suggest a modelling and design technique for a demonstrably complete and correct system for providing logical access control in a shared data base system.

(D. K. Hsiao, E. J. McCauley)

PARALLELISM IN COMPUTER PROGRAMS

In 1966 Hellerman proposed a computer design with several arithmetic units instructed from a single requential program to perform several computations in parallel. One of the early results of the present research has been a technique for the minimization of resources required for minimum time evaluation of algebraic expressions on this Hellerman computer. The generalization of this result to branch-free programs depends on a result of Aho Sethi and Ullman, that storage

conflicts resulting from multiple uses of a variable name can be avoided by systematic renaming of variables. Identification of independent uses of variable names has been shown feasible in smooth programs, that is programs composed of basic blocks combined into two-terminal networks by the operations of concatenation, alteration and iteration. In a smooth program it is possible to find for each computation a set of appropriate basic blocks. Two computations either share such a set or have disjoint sets. The technique for resource minimization of branch free programs applies to each set of appropriate basic blocks, and thus generalizes to smooth programs.

(C. R. Foulk, O. C. Juelich)

THE PL/X COMPILER

The PL/X is a programming language whose syntax is, to a large extent, the syntax of the PL/1. The PL/X compiler is produced by means of a compiler-writing system, known as XPL. The compiler runs on an IBM 370/165 computer system under the OS MVT and generates object modules in DEC System-10 machine code.

The goal of the project is to produce a PL/1-like systems programming language for the DEC System-10 computer. The project work has been completed. Two documentations entitled The PL/X Programming Language Reference Manual and The PL/X Compiler-Subsystem Writers' Manual are available for general reference.

(D. K. Hsiao, H. Su, E. W. Leggett, et. al.)

PROGRAM OPTIMIZATION FOR VIRTUAL MEMORY

We are primarily interested in optimizing programs to reduce the page fault rate of a virtual memory system. We have the following results:

1. An optimal partitioning algorithm for assigning nodes in a series parallel computer flowgraph to pages.
2. A partitioning algorithm for assigning nodes an an arbitrary computer flowgraph to pages.
3. A partitioning algorithm for assigning subroutines of a computer flowgraph to pages.

The effects of these partitioning algorithms on paging performance are also investigated.

(C. R. Foulk, H. Y. Su)

A SMOOTHNESS INDEX FOR COMPUTER FLOWGRAPHS

'Flow of control' is an important property of programming languages. The control structures permissible in a programming language may exert strong influences on such matters as:

easy comprehension of source text in the language
debugging processes
compile-time optimization
run-time storage management.

This research is about flowgraphs. A graph grammar, SG, is defined. The productions of SG correspond to the basic and familiar operations of:

concatenation = normal sequencing
alternation = if-then-else
iteration = looping.

The 'language' produced by this grammar is the set of all flowgraphs which can be generated by these three operations only.

A smooth flowgraph is defined as one which is generable by SG.

An algorithm is being developed to recognise a smooth flowgraph. This algorithm is, essentially, a 'top-down' parser for the grammar, SG.

Another algorithm is also being developed to transform a non-smooth flowgraph into a smooth one.

No restriction is placed on the flowchart which forms the input to the transformation algorithm mentioned above. Hence, the flowchart may be large and complex. To reduce the complexity of the transformation algorithm, the input flowgraph is systematically partitioned into smaller subgraphs, using the 'interval' concept defined by Cocke and Allen.

The output of the transformation algorithm is always a smooth flowgraph which is 'equivalent' (in the sense of execution sequences) to the input flowgraph.

The results of the two algorithms may be extended to obtain a smoothness index for flowgraph programs.

(C. R. Foulk, O. Lange)

THEORETICAL FOUNDATIONS FOR CONTEXT PROTECTION AND CONSISTENT CONTROL IN DATA SECURE SYSTEMS

In data secure systems, the basic unit of information for protection is called a data unit, which may be a single data item or a collection of data items having the same properties with respect to access control.

Context protection means that the same data unit may be protected differently in different contexts. For example, the same data field may be protected differently in two different records. The difference may be determined by the manner in which the fields and records are being accessed.

Consistent control is concerned with the problem that when new data units based on the old data units of the data base are created by the users, these data units must be protected consistently in the sense that their access requirements must be generated automatically and be conformed with the access requirements of the old data units.

Both context protection and consistent control can be enforced by means of certain built-in relations among the data units involved. These relations under certain conditions can cause deadlock-like situations should there be any violation of context protection and consistent control. The study is concentrated on the conditions in which these deadlock-like situations must occur, and the theoretical treatments on the creation and effectiveness of the built-in relations. A graph-theoretic approach is being used for this study.

(D. K. Hsiao, C. J. Nee)

## IX. JOINT PROGRAMS

### A MANAGEMENT GAME FOR IMPROVING INFORMATION RETRIEVAL SYSTEM MANAGEMENT DECISION-MAKING

A management game is designed to train the game player in the role of manager of an information retrieval system which will provide current awareness services for a university. The management game is a non-competitive, dynamic game played through time involving the game player and the computer.

The game player's major tasks are to design, to develop, and to manage the information retrieval system. In this context, the game player is a decision-maker. At various decision points, during the development and/or operation of the information retrieval system, he may indicate modifications to his system for the next time period, i.e., maintain or modify current policies or initiate new policies, based on periodic statistics outputted by the computer.

Evaluation of the game player will be made by measuring the amount of learning or non-learning from one decision point to the next. Learning in the sense of developing and improving decision-making skills or effectiveness can be determined by examining the consequences of the game player's decisions, i.e., the benefits to the information retrieval system resulting from his decisions which were based on the information periodically presented to him. A similar analogy applies to non-learning. Thus, evaluation of the game player is conducted through a cost-benefits analysis of the information retrieval system he has designed, developed, and managed.

(G. J. Lazorick, M. J. Lee)

### SOCIOLOGICAL RESEARCH

Research on the diffusion of MIC's Current Awareness Service has been conducted. MIC measured the acceptance of the Current Awareness Service by various faculty members exposed to a blitz-type program and correlated that acceptance with the following factors, or attributes, of the individual faculty member: (1) proneness to accept change, (2) relative centrality within a given department (as measured by peer-nomination), (3) demographic data, (4) degree of cosmopolitanism, and (5) information sources.

A group of 272 OSU faculty was administered a questionnaire covering the above five factors. After the questionnaire was administered the same faculty were invited to use the system. An individual's time-of-adoption served as the dependent variable. The previously mentioned questions served as predictors. In addition a follow-up questionnaire was administered to patrons to provide longitudianl data. Particular emphasis was given to an analysis of changes in their evaluation of computerized literature searches. Analysis was related back to the pre-measure on the notification variables.

Analysis focused on three major themes found in the diffusion literature: 1) characteristics of adopters vs. non-adopters; 2) relative centrality of adopters vs. non-adopters; and 3) the effect of context on the adoption of an innovation. While value orientations and demographic and professional background characteristics were of little aid in predicting adoption or non-adoption, centrality and context were found to be significant predictors. The study was relatively unique methodologically in that measures of characteristics and centrality were obtained prior to the introduction of the innovative service to the subject population rather than on an ex post facto basis.

(L. W. Stern, C. S. Craig, A. J. LaGreca, R. G. Salem)

# APPENDIX A

## COMPUTER AND INFORMATION SCIENCE COURSE LISTING

## BY NUMBER AND TITLE

201 Elementary Digital Computer Programming

222 Programming and Algorithm II (Added Summer 1973)

240 Computer Programming and Data Processing I (Changed Summer 1973 to, 211 Computer Data Processing I)

241 Digital Computer Programming I (Changed Summer 1973 to, 221 Programming and Algorithms I)

311 Introduction to File Design and Analysis

411 Design of On-Line Systems

422 Topics in Computing for Engineers

440 Computer Programming and Data Processing II

494 Group Studies

505 Fundamental Concepts of Computer and Information Science

509 Survey of Computer and Information Science for High School Teachers

541 Survey of Numerical Methods

542 Introduction to Computing in the Humanities

543 Intermediate Digital Computer Programming

548 Digital Computer Programming for High School Teachers

549 Numerical Analysis for High School Teachers

550 Introduction to Information Storage and Retrieval

555 Survey of Programming Languages

594 Group Studies

610 Principles of Man-Machine Interaction

640 Numerical Analysis

641 Computer Systems Programming I

642 Numerical Linear Algebra

643 Linear Optimization Techniques in Information Processing

644 Advanced Computer Programming

652 Modeling of Information Systems

675 Digital Computer Organization

680 Data Structures

693 Individual Studies

694 Group Studies

705 Mathematical Foundations of Computer and Information Science (Title changed Summer 1973)

706 Information Theory in Behavioral Science

712 Man-Machine Interface

720 Introduction to Linguistic Analysis

726 Theory of Automata I (Theory of Finite Automata)

727 Theory of Automata II (Turing Machines and Computability)

728 Theory of Automata III (Topics in Theory of Computability)

730 Basic Concepts in Artificial Intelligence

735 Statistical Methods in Pattern Recognition

740 Computer Systems Programming II

741 Comparative Operating Systems

745 Numerical Solution of Ordinary Differential Equations

746 Advanced Numerical Analysis

750 Modern Methods of Information Storage and Retrieval

751 Fundamentals of Document-Handling Information Systems

752 Techniques for Simulation of Information Systems

753 Theory of Indexing

754 Language Processing for Information Storage and Retrieval

755 Programming Languages

756 Compiler Design and Implementation

760 Selected Topics in the Mathematics of Information Handling

765 Theory of Management Information Systems

775 Advanced Computer Organization

780 File Structures

788 Intermediate Studies in Computer and Information Science

793 Individual Studies

794 Group Studies

797 Interdepartmental Seminar

805 Information Theory in Physical Science

806 Cellular Automata and Models of Complex Systems

812 Computer and Information Science Research Methods

820 Computational Linguistics

835 Special Topics in Pattern Recognition

840 Operating System Implementation

845 Numerical Solution of Partial Differential Equations

850 Theory of Information Retrieval I

851 Theory of Information Retrieval II

852 Design and Analysis of Information Systems Simulation

855 Formal Theory of Programming Languages

865 Seminar on Socio-Psychological Aspects of the Information Sciences

880 Advanced Theory of Computability

888 Advanced Studies in Computer and Information Science

889 Advanced Seminar in Computer and Information Science

899 Interdepartmental Seminar

994 Group Studies

999 Research

# APPENDIX B

## COMPUTER AND INFORMATION SCIENCE FACULTY

Marshall C. Yovits, Ph. D., (Yale University).
Professor and Chairman of Department of Computer and Information Science and Professor of Electrical Engineering. Director, C.I.S. Research Center. Information systems, theory of the flow of information, self-organizing systems.

Ranko Bojanic, Ph.D., (Mathematical Institute of the Serbian Academy of Science).
Professor of Computer and Information Science and Professor of Mathematics. Mathematical analysis, theory of approximation.

Richard I. Hang, M.S., (The Ohio State University).
Professor of Computer and Information Science and Professor of Engineering Graphics. Computer graphics, engineering application of computers.

Clyde H. Kearns, M.S., (The Ohio State University).
Professor of Computer and Information Science and Professor of Engineering Graphics. Computer graphics, engineering application of computers.

Robert B. McGhee, Ph.D., (University of Southern California).
Professor of Computer and Information Science and Professor of Electrical Engineering. Control theory, switching theory, logical design.

Harold B. Pepinsky, Ph.D., (University of Minnesota).
Professor of Computer and Information Science and Professor of Psychology. Clinical and socio-cultural psychology.

Roy F. Reeves, Ph.D., (Iowa State University).
Professor of Computer and Information Science and Professor of Mathematics. Director, Instruction and Research Computer Center. Numerical analysis and programming.

Jerome Rothstein, A.M., (Columbia University).
Professor of Computer and Information Science and Professor of Biophysics. Informational problems in science, methodology, biocybernetics.

Charles Saltzer, Ph.D., (Brown University).
Professor of Computer and Information Science and Professor of Mathematics. Coding Theory, numerical analysis, automata theory.

Balakrishnan Chandrasekaran, Ph.D., (University of Pennsylvania).
Associate Professor of Computer and Information Science. Pattern recognition and artificial intelligence, learning automata theory, finite memory decision theory, and game theory.

Kenneth J. Breeding, Ph.D., (University of Illinois).
Associate Professor of Computer and Information Science and Associate Professor of Electrical Engineering. Computer organization and Switching Theory.

Ronald L. Ernst, Ph.D., (University of Wisconsin).
Associate Professor of Computer and Information Science and Associate Professor of Psychology. Human performance theory and engineering, complex information processing and systems evaluation.

Clinton R. Foulk, Ph.D., (University of Illinois).
Associate Professor of Computer and Information Science. Programming languages, systems programming, with emphasis on algorithms for parallel compilation.

David K. Hsiao, Ph.D., (University of Pennsylvania)
Associate Professor of Computer and Information Science. Systems programming, information storage and retrieval systems, file systems, data base management systems, access control and privacy protection of data, data definition language and processor, system architectures.

Douglas S. Kerr, Ph.D., (Purdue University).
Associate Professor of Computer and Information Science. Numerical analysis and programming. Director, N.S.F. sponsored Summer Institue in Computer and Information Science for High School Teachers, 1970.

Gerald J. Lazorick, Ph.D., (State University of New York at Buffalo).
Associate Professor of Computer and Information Science and Associate Professor of Library Administration. Director, Mechanized Information Center. Information storage and retrieval, library systems: design and analysis.

Ming-Tsan Liu, Ph.D., (University of Pennsylvania).
Associate Professor of Computer and Information Science. Computer organization, switching and automata theory, mathematical programming, computer architecture, pseudo-Boolean programming, threshold logic.

Anthony E. Petrarca, Ph.D., (University of New Hampshire).
Associate Professor of Computer and Information Science. .Automatic indexing, chemical structural information processing, automated search systems, other aspects of information storage and retrieval.

James B. Randels, Ph.D., (The Ohio State University).
Associate Professor of Computer and Information Science and Assistant Director, Learning Resources Computer Center. Computer operating systems and utilities, telecommunications applications, subroutine libraries, programming languages.

James E. Rush, Ph.D., (University of Missouri).
Associate Professor of Computer and Information Science. Indexing theory, automated language processing, organization of information, and parallel processing.

Celianna Taylor, B.S.L.S., Graduate School of Library Science, Case-Western Reserve University; Senior Research Associate and Associate Professor of Library Administration. Information dissemination systems, information centers, library systems and management.

Lee J. White, Ph.D., (University of Michigan).
Associate Professor of Computer and Information Science and Associate Professor of Electrical Engineering. Mathematical programming, data structures, organization of information.

Ronald L. Wigington, Ph.D., (University of Kansas).
Adjunct Associate Professor of Computer and Information Science; Director of R. & D., Chemical Abstracts Service. Computer system design.

Alan W. Biermann, Ph.D., (University of California, Berkeley).
Assistant Professor of Computer and Information Science. Theory of computer systems, formal systems.

F. William Buttelmann, Ph.D., (University of North Carolina).
Assistant Professor of Computer and Information Science. Automata theory, computer architecture and programming languages.

Thomas G. DeLutis, Ph.D., (Purdue University).
Assistant Professor of Computer and Information Science. Design and evaluation of information systems; systems programming.

Harvey S. Koch, Ph.D., (Pennsylvania State University). Appointed Autumn 1973
Assistant Professor of Computer and Information Science. Data definition language, data base management, programming languages and compiler design.

Frederick S. Koehl, Ph.D., (The Ohio State University).
Assistant Professor of Computer and Information Science and Math Analyst, Instruction and Research Computer Center. Sorting techniques, topological groups, compiler design.

Robert F. Mathis, Ph.D., (The Ohio State University).
Assistant Professor of Computer and Information Science. Programming languages, numerical analysis.

Larry Reeker, Ph.D., (Carnegie-Mellon University).
Assistant Professor of Computer and Information Science and Assistant Professor of Linguistics. Infinite automata, formal language theory, foundations of linguistic theory, language acquisition by children.

Frederick A. Stahl, Ph. D., (University of Illinois). Appointed Autumn 1973
Assistant Professor of Computer and Information Science.
Computational security, cryptography, information retrieval, computers in the humanities, and in the law, artificial intelligence.

William M. Wagner, Ph.D., (Iowa State University)
Adjunct Assistant Professor of Computer and Information Science and Math Analyst, Instruction and Research Computer Center. Systems programming and numerical analysis.

Donald L. Kalmey, M.S., (The Ohio State University).
Counselor.

Ernest Staveley, B.S., (U.S. Naval Postgraduate School).
Administrative Assistant, and Assistant Director, C.I.S. Research Center.

## APPENDIX C

### COMPUTER AND INFORMATION SCIENCE RESEARCH CENTER SENIOR PERSONNEL

The Computer and Information Science Research Center is directed by Dr. Marshall C. Yovits who is also chairman of the Department of Computer and Information Science at The Ohio State University. As noted on page 7 of this report, the research staff consists of faculty and graduate students of the Department of Computer and Information Science, as well as faculty and graduate students from other University departments dealing with specific applications of computer and information science.

Listed below are the principal investigators for various research activities. The department (or organization) with which each principal investigator is affiliated as indicated.

Alan W. Biermann, Computer and Information Science

H. Richard Blackwell, Biophysics

H. William Buttelmann, Computer and Information Science

Balakrishnan Chandrasekaran, Computer and Information Science

Thomas G. DeLutis, Computer and Information Science

Ronald L. Ernst, Computer and Information Science

Clinton R. Foulk, Computer and Information Science

Douglas S. Kerr, Computer and Information Science

Gerald J. Lazorick, Computer and Information Science

Ilse Lehiste, Linguistics

Ming-Tsan Liu, Computer and Information Science

Robert B. McGhee, Electrical Engineering

Robert F. Mathis, Computer and Information Science

Anthony E. Petrarca, Computer and Information Science

Larry H. Reeker, Computer and Information Science

Jerome Rothstein, Computer and Information Science

James E. Rush, Computer and Information Science

Charles Saltzer, Mathematics

Celianna I. Taylor, Library Administration, Computer and Information Science

Lee J. White, Computer and Information Science

Marshall C. Yovits, Computer and Information Science

## APPENDIX D

### COMPUTER AND INFORMATION SCIENCE SEMINAR SERIES

July 3, 1972 "Text Compaction," William S. Stalcup, Ph.D. Candidate, The Ohio State University.

July 10, 1972 "Evaluation of Information Retrieval Systems," Jun Matsumura, The Ohio State University.

August 3, 1972 "The Analysis of Pragmatic Information," Bruce J. Whittemore, Ph.D. Candidate, The Ohio State University.

October 12, 1972 "Promotion of SDI (Selective Dissemination of Information) Services and Assessment of User Satisfaction," Professor Louis W. Stern, The Ohio State University.

October 19, 1972 "Computer Program Synthesis from Computation Traces," Professor Alan W. Biermann, The Ohio State University.

November 2, 1972 "An Effective Heuristic Procedure for Solving the Traveling Salesman Problem," Dr. Shen Lin, Bell Telephone Laboratories.

November 9, 1972 "Recent Developments in Computer Networks," Professor Ming T. Liu, The Ohio State University.

November 16, 1972 "Design and Evaluation of an Automatic Abstracting System," Betty A. Mathis, Ph.D. Candidate, The Ohio State University.

November 17, 1972 "Successive Overrelaxation Revisited," Professor Richard S. Varga, Kent State University.

January 11, 1973 "Some Problems of the Language and Logic of Parallel Computations," Professor Jerome Rothstein, The Ohio State University

January 18, 1973 "Design and Implementation of Language Analysis Procedures with Applications to Automatic Indexing," Carol E. Young, Ph.D. Candidate, The Ohio State University.

January 25, 1973 "Resolution-Based Proof Procedures in First-Order Logic," David Gelperin, Ph.D. Candidate, The Ohio State University.

February 1, 1973 "A Formal Model for Semantics in Translating Very Simple Programming Languages," Professor H. William Buttelmann, The Ohio State University.

February 8, 1973 "Implications of Computerized Medical Records on Health Care Delivery," Robert C. Chase, Associate Director, Biometrics Laboratory, The Ohio State University.

February 15, 1973 "Computer Analysis of Extra-Terrestrial Radio Signals," Robert S. Dixon, Assistant Director, Radio Observatory, and Mathematics Analyst, Instruction and Research Computer Center, The Ohio State University.

March 1, 1973 "Impact of Usage Feedback on Redesign of Battelle's On-Line Interactive Information Retrieval System," John Fried, Chief, Division of Computerized Information Services, Battelle Memorial Institute.

March 6, 1973 "Local Approach to Problem Solving and Control," Dr. V.L. Stefanjuk, Institute for Information Transmission Problems Academy of Science, U.S.S.R.

March 7, 1973 "Techniques for Compressing Bound-Context Acceptors," Marshall Mickunas, Purdue University.

March 28, 1973 "Computer-Based Analytic Grading for German Grammar Instruction," Dr. David R. Levine, Stanford University.

April 3, 1973 "A Search Strategy for a Deductive Question - Answering System," Daniel Fishman, University of Maryland.

April 5, 1973 "Decision Table Programming Languages," Dr. John Metzner, Ordianance Research Laboratory, Pennsylvania State University.

April 12, 1973 "Everything You Wanted to Know About Automatic Theorem Proving (... Well, Almost Everything) But Were Afraid to Ask," David Gelperin, Ph.D. Candidate, The Ohio State University.

April 19, 1973 "Smooth Programs," Professor Clinton R. Foulk, The Ohio State University.

April 24, 1973 "Proving Properties of Concurrent Processes," Glen Newton, University of Iowa.

April 26, 1973 "Non Computational Aspects of a University Computer Center," J. Carroll Notestine, Director, University Systems Computer Center, The Ohio State University.

May 3, 1973 "Recent Developments in Data Description Languages," Professor Thomas G. DeLutis, The Ohio State University.

May 10, 1973 "Some Interesting Computer Applications and Their Value to the Everyday Operations of a Large Chemical Company," Richard Klimpel, Ph.D., Research Manager, Mathematical Applications Division, Computation Research Laboratories, Dow Chemical Company.

May 16, 1973 "Independent Data Definition for Cobol and Fortran," Harvey Koch, Penn State.

May 17, 1973 "Pattern Recognition of Three-Dimensional Objects," Professor Kenneth J. Breeding, The Ohio State University.

May 24, 1973 "Computations on Sparce Matrices," Paul Wang, Ph.D. Candidate, The Ohio State University.

# APPENDIX E

## RELATED ACTIVITIES OF THE STAFF OF

## COMPUTER AND INFORMATION SCIENCE RESEARCH CENTER

E. BAMMEL; J. ROTHSTEIN presented "A Fast Algorithm for Determining Equivalences of Matrices of L's and 1's under Arbitrary Row and Column Permutation with Application to Enumeration of the Latin Squares of Order 9 and the Graph Isomorphism Problem", at the Computer Science Conference, in Columbus, Ohio, Febraury 20-22, 1973.

R. BARNEY presented "Time Relationships in the English Sentence" at the Computer Science Conference in Columbus, Ohio, February 20-22, 1973

H. BUTTELMANN presented "A Formalization of the Language Translation Process which Appears Generalizable", at the Computer Science Conference, in Columbus, Ohio, February 20-22, 1973.

H. BUTTELMANN attended the Fifth Annual Symposium on Theory of Computing at Austin, Texas, April 30-May 2, 1973, sponsored by the Special Interest Group on Automata and Computing Theory of the Association for Computing Machinery.

A. W. BIERMANN is the principal investigator for a grant from the National Science Foundation to study "Self Programming Systems: A New Approach" during the period 1972-73.

A. W. BIERMANN presented a paper entitled, "An Interactive Finite' State Language Learner" at the First U.S.A.-Japan Computer Conference, October 3-5 in Tokyo, Japan. On October 10, he participated in a symposium on the Mathematical Theory of Computation at the University of Kyoto, Kyoto, Japan and gave a lecture entitled "Computer Program Synthesis from Computation Traces". On October 11, he participated in a panel discussion with other scholars from the United States and Japan on trends in the mathematical theory of computation. The proceedings from this discussion will appear in the Japanese computer science magazine, BIT.

A. W. BIERMANN presented "An Approach to the Design of Trainable Machines", at the 1973 Southeastern Symposium on System Theory, in Raleigh, N.C., March 22-23, 1973.

B. CHANDRASEKARAN was awarded a grant from the Air Force Office of Scientific Research for research on pattern recognition entitled "Aspects of Decision Theory with Applications to Pattern Recognition and Digital Communications".

B. CHANDRASEKARAN was appointed Associate Editor of the IEEE Transactions: System, Man and Cybernetics.

B. CHANDRASEKARAN was appointed chairman, Wiener Commemorative Symposium to be held in Boston, November 7, 1973.

B. CHANDRASEKARAN reviewed papers for IEEE Transactions: Information Theory, IEEE Transactions: Systems, Man and Cybernetics, and ACM Computing Reviews.

B. CHANDRASEKARAN presented "Artificial Intelligence -- the Case for Agnosticism," at the Raman Research Institute, in Bangalore, India, October 20, 1972. He also presented "Finite Memory Decision Theory," at the Indian Institute of Science, in Bangalore, India, October 21.

B. CHANDRASEKARAN presented the paper, "Conditions for Perfect Discrimination for Independent Measurements" (co-author, A.K. Jain, Graduate Student, Department of Computer and Information Science) at the International System Science Conference, University of Hawaii, Honolulu, Hawaii, January 9, 1973.

B. CHANDRASEKARAN; D. GELPERIN presented "Clause Elimination in Resolution Theorem Proving", at the Computer Science Conference, in Columbus, Ohio, February 20-22, 1973.

A. DE FANTI presented "Some Considerations for Providing Extensibility and Habitability in a Mini-Computer Graphics System", at the Computer Science Conference, in Columbus, Ohio, February 20-22, 1973.

C. R. FOULK presented "Smooth Programs", at the Computer Science Conference, in Columbus, Ohio, February 20-22, 1973.

C. R. FOULK served as chairman of the Book Exhibits Committee, at the Computer Science Conference, in Columbus, Ohio, February 1973.

M. L. GILLENSON, presented "The Generation of the Human Face on a CRT", at the Computer Science Conference, in Columbus, Ohio February 20-22, 1973.

D. K. HSIAO presented an invited talk: "Logical Access Control and Protection Mechanisms in Computer Systems," at the Naval Ship Research and Development Center and Office of Naval Research, Washington, D.C., September 26, 27, 28, 1972.

D. K. HSIAO's paper entitled, "Data Management with Variable Structure and Rapid Access" was presented at the First U.S.A.-Japan Computer Conference sponsored by the American Federation of Information Processing Societies and the Information Processing Society of Japan. The paper is included in the proceedings of the Conference. The Conference was held in Tokyo, Japan, October 3-5, 1972. (co-author, F. Manola)

D. K. HSIAO had his paper on "Data Base and File Management," presented to the Society of Management Engineering of Japan, in Tokyo, October 6-7, 1972 by student Frank Manola.

D. K. HSIAO attended a workshop by invitation on Controlled Accessibility, December 10-13 at Rancho Santa Fe, California. The workshop was sponsored in part by the National Science Foundation and organized by the National Bureau of Standards and the Association for Computing Machinery.

D. K. HSIAO received a grant from the Office of Naval Research for research in data secure computer systems.

C. H. KEARNS has been appointed treasurer and circulation manager for two years of the Engineering Design Graphics Journal, published by the American Society for Engineering Education.

D. S. KERR was elected chairman of the Central Ohio Chapter of the Association for Computing Machinery.

D. S. KERR was appointed Chairman of the Fourth Symposium on Computer Science Education to be held in Detroit, Michigan, February 14 and 15, 1974. The Symposium is sponsored by the Special Interest Group on Computer Science Education of the Association for Computing Machinery.

D. S. KERR served as a member of the planning committee of the Third SIGCSE Technical Symposium on Computer Science Education and as chairman of the session on Systems Courses, Columbus, Ohio, February 20-22, 1973.

D. S. KERR attended the ACM SIGARCH-SIGOPS workshop on "Virtual Computer Systems" at Harvard University, March 26-27, 1973 and the ACM SIGFIDET Work Session on "The Information System and Data Base Management" in New York City, March 29, 1973.

D. S. KERR participated in a panel discussion on "A Graduate Program in Computer Science" at the National Computer Conference, New York, June 4-8, 1973.

G. J. LAZORICK; C. S. CRAIG; A. J. LA GRECA; L. W. STERN presented "A Perceptual Evaluation of a Selective Dissemination of Information System", at the Computer Science Conference, Columbus, Ohio, February 20-22, 1973.

G. J. LAZORIK participated in a panel discussion culminating a seminar series on Specialized Information Systems, sponsored by the Central Ohio Chapter of the American Society for Information Science, Columbus, Ohio, March 27, 1973.

B. A. MATHIS; H. F. MATHIS presented "Women Enrolled in Engineering Curricula", at the 80th Annual Conference of the American Society for Engineering Education, at Texas Tech University, June 20, 1972. They also presented the same paper at the Engineering Foundation Conference on Women in Engineering and Management, at New England College, Hennecker, N.H., July 16-21, 1972.

B. A. MATHIS; J. E. RUSH presented "Automatic Abstracting and Indexing IX, Design and Evaluation of an Automatic Abstracting System", at the Computer Science Conference, Columbus, Ohio, February 20-22, 1973.

B. A. MATHIS; C. E. YOUNG received honorable mention for their paper, "Improvement of Automatic Abstracts by the Use of Structural Analysis", submitted to the American Society for Information Science Student Paper Contest.

R. F. MATHIS served as chairman of an ASEE Symposium on Creative Teaching held at The Ohio State University, November 3, 1972.

R. F. MATHIS served as Secretary-Treasurer and Local Committee Chairman for the Computer Science Conference held in Columbus, Ohio, February 20-22, 1973.

R. F. MATHIS served as a judge for the Central Ohio Science Day, held in Columbus, Ohio, March 10, 1973.

R. F. MATHIS served as Session Chairman at the North Central Section meeting of ASEE, held in Dayton, Ohio, April 13, 1973.

R. F. MATHIS was Panel Speaker at the Campus Activity Coordinator's Workshop, ASEE National Meeting, held in Ames, Iowa, June 24, 1973.

R. F. MATHIS was chosen Outstanding Campus Activity Coordinator of the Year by ASEE.

R. F. MATHIS attended the following conferences: ACM 1972, Boston, Massachusetts, August 13-17, 1972; the Symposium on Creative Teaching, Columbus, Ohio, November 3, 1972; FJCC 1972, Anaheim, California, December 4-7, 1972; the Computer Science Conference, Columbus, Ohio, February 20-22, 1973; SIGCSE, Third Technical Symposium, Columbus, Ohio, February 22-23, 1973; the Frontiers in Education, Purdue University, April 9-11, 1973; North Central Section ASEE, Dayton, Ohio, April 13-14, 1973; NCC, New York, New York, June 4-8, 1973; the Seminar on Managing the Impact of Generalized Data Bases, New York, New York, June 7-8, 1973; ASEE National Meeting, Ames, Iowa, June 24-28, 1973.

R. F. MATHIS consulted with the following universityies with regard to undergraduate programs in Computer and Information Science: Illinois State University, Normal, Illinois, March 21-23, 1973; Oakland University, Rochester, Michigan, April 5-6, 1973; Purdue University, Calumet Campus, Hammond, Indiana, May 24, 1973.

A. E. PETRARCA was program chairman and local arrangements chairman for the Winter Chemical Literature Conference sponsored by the American Chemical Society Division of Chemical Literature at The Ohio State University, Columbus, Ohio, March 14-17, 1973. He also chaired a session on "New Directions in University Research" at the Conference.

L. H. REEKER presented "Information Measures and Recursive Functions" the Computer Science Conference held in Columbus, Ohio, February 20-22, 1973.

L. H. REEKER presented "The Problem Solving Theory of Syntax Acquisition" at Washington State University, Pullman, Washington on April 23, 1973, and at the Naval Postgraduate School, Monterey, California on April 26, 1973.

L. H. REEKER was reappointed editor of SIGACT News, published by the Special Interest Group on Automata and Computability Theory of the Association for Computing Machinery, at the Fifth Annual Theory of Computing Symposium, Austin, Texas, April 30-May 2, 1973.

J. ROTHSTEIN presented a paper, "Relativity Impliers Irreversibility" before the annual meeting of the American Physical Society in New York City, January 31, 1973.

J. ROTHSTEIN; F. DICKEY presented "Pascal's Triangle and Generalized Fibonacci Numbers, Integer Representations and Adders", at the Computer Science Conference, Columbus, Ohio, February 20-22, 1973. J. Rothstein also presented "Relational Languages: Formal Languages with Metalinguistic Extensibility: at the conference.

J. ROTHSTEIN presented a paper, "Formal Language Admitting Reductionism, Holism, Synthesis, and Open-Ended Hierarchical Complexity" before the seventeenth annual meeting of the Biophysical Society, Columbus, Ohio, February 27 through March 2, 1973.

J. ROTHSTEIN participated as a panel member and discussant, in a session entitled "New Directions in University Research" at the Winter Conference of the Division of Chemical Literature of the American Chemical Society ath The Ohio State University, Columbus, Ohio, March 14-17, 1973.

J. ROTHSTEIN presented "Loschmidt's and Zermelo's Paradoxes Do Not Exist", at the American Physical Society meeting, in Washington, D.C., April 23-26, 1973.

J. ROTHSTEIN spoke on "Patterns, Algorithms, and Aspects of Parallel Computation" at the Computer Science Seminar, Bell Telephone Laboratories, Murray Hill, New Jersey, on April 27, 1973.

J. E. RUSH chaired a session on Output Forms and Languages, at the Gordon Research Conference on Scientific Information Problems in Research, in New London, New Hampshire, July 10-14, 1972.

J. E. RUSH; E. YOUNG presented "Automatic Abstracting and Indexing. X. Design and Implementation of Language Analysis Procedures with Application to Automatic Indexing", at the Computer Science Conference, in Columbus, Ohio, February 20-22, 1973.

J. E. RUSH chaired a two-day session of the Publications Committee of the American Society for Information Science in Washington, D. C., March 24-25, 1973.

J. E. RUSH moderated a panel discussion culminating a seminar series on Specialized Information Systems, sponsored by the Central Ohio Chapter of the American Society for Information Science, in Columbus, Ohio, March 27, 1973.

D. H. Y. SU presented "Optimization of Smooth Linear Programs for Virtual Memory", at the Computer Science Conference, in Columbus, Ohio, February 20-22, 1973.

C. I. TAYLOR was appointed chairman of the United Community Council Subcommittee for Design of an Information and Referral System, July 1972.

C. I. TAYLOR was appointed as a Consultant half-time with the Academy for Contemporary Problems, Columbus, Ohio, September 1, 1972 through June 30, 1973.

P. T. R. WAND; D. S. KERR; L. J. WHITE presented "An Improved Algorithm for the Bandwidth Minimization of Sparse Matrices", at the Computer Science Conference, Columbus, Ohio, February 20-22, 1973.

L. J. WHITE presented a paper, "Optimum Concentration Location in Telecommunications Design" at the SIGMAP meeting, Association for Computing Machinery Annual Conference, August 14, 1972.

L. J. WHITE presented the paper, "Stability Analysis of Non_Statistical Classification Algorithms" at the Section of Mathematical Sciences 82nd Annual Meeting of the Ohio Academy of Science, at John Carroll University, Cleveland, Ohio, April 27, 1973.

B. J. WHITTEMORE received honorable mention for his paper, "Executional Uncertainty in Decision-Making", submitted to the American Society for Information Science Student Paper Contest.

M. C. YOVITS was named as one of the two co-editors of the series, Advances in Computers, published by Academic Press Inc.

M. C. YOVITS was selected to be a member of the Conferences and Symposia Committee and as a member of the three-man Program Perspective Subcommittee of the Association for Computing Machinery.

M. C. YOVITS presented a paper, "A Generalized Concept for the Analysis of Information", co-author, B. J. Whittemore, at the NATO Advanced Study Institute in Information Science, Seven Springs, Champion, Pennsylvania, August 22, 1972.

M. C. YOVITS has been made chairman of the Association for Computing Machinery 73 Research Abstract Sessions Program, Atlanta, Georgia, August 27-29, 1973.

M. C. YOVITS spoke on career opportunities that exist in Computer and Information Science, at a meeting of the Society of Physics Students from Ohio, Michigan, West Virginia, Indiana, Kentucky, and Pennsylvania, at Wright State University, November 4, 1972.

J. C. YOVITS served as general chairman of the computer Science Conference, Columbus, Ohio, February 20-22, 1973.

M. C. YOVITS; J. G. ABILOCK presented "The Determination of an Information Profile for a Data Set", at the Computer Science Conference, Columbus, Ohio, February 20-22, 1973.

M. C. YOVITS gave a seminar talk on "A Generalized Conceptual Development for the Analysis and Flow of Information", at the Library and Information Science Doctoral Program Seminar, at Case Western Reserve University, April 4, 1973.

## VISITORS

Visitors to the Department of Computer and Information Science on August 21 and 22, 1972 were Daniel Conlon and Daniel Kayser, Assistant Professors from the University of Paris. They are compiling a comprehensive report on research in computer-aided instruction in North America. They are sponsored by the French Research Committee on Information, and have visited 20 universities, institutes, and industrial sites in search of information for their report.

# APPENDIX F

## PUBLICATIONS OF THE COMPUTER AND INFORMATION SCIENCE RESEARCH CENTER STAFF[1]

BOJANIC, R. A note on the precision of interpolation by Hermite-Fejer polynomials. In: Proceedings of the Conference on Constructive Theory of Functions, August 24-September 3, 1969, Akademiai Kiado, Budapest, 1972. p. 69-76.

BOJANIC, R.; SHISHA, O. On the precision of uniform approximation of continous functions by certain positive linear operators of convolution type. Journal of the Approximation Theory, 8 (1972).

BIERMANN, A. W. On the inference of turing machines from sample computations. Artificial Intelligence, 3:3 (Fall 1972).

BLUMBERG, J. W. ; FOULK, C. R. A not on "A modification of Nordsieck's method using an 'off-step'point". Communications of ACM, 14:12 (Dec. 1971) p. 796.

CHANDRASEKARAN, B.; LARN, C. C. A deterministic finite memory algorithm for the symmetric hypothesis testing problem. Abstracts of the International Information Theory Symposium, Ashkelon, Israel, June 1973.

CHANDRASEKARAN, B.; JAIN, A. K. General conditions for perfect discrimination for independent measurements. In: Proceedings of the International Conference on System Sciences, Honolulu, Hawaii, January, 1973.

CHANDRASEKARAN, B. ; KANAL, L. On linguistic, statistical and mixed models for pattern recognition. In: Frontiers of Pattern Recognition, (Edited by S. Watanabe) Academic Press, 1972.

CHIOU, W. Toward a complete theory of spatioal organization of the human visual system at impulse detection threshold. Doctoral dissertation. The Ohio State University, 1973.

DE FANTI, T. A. The graphics symbiosis system - an interactive mini-computer animation graphics language designed for habitability and extensibility. Doctoral dissertation. The Ohio State University, 1973.

ERNST, R. L. ; YOVITS, M. C. Information science as an aid to decision-making. In: Decision-making: creativity, judgment, and systems, (edited by Henry S. Brinkers) Columbus, Ohio, The Ohio State University Press, 1972.

[1] See Appendix G for publications issued as part of the Computer and Information Science Research Center technical report series.

GELPERIN, D. Single parent elimination in resolution. SIGART Newsletter 28 (June 1972)

GELPERIN, D. H. Clause deletion in resolution theorem proving. Doctoral dissertation. The Ohio State University, 1973.

HARRIS, D. R. GOLDA: A graphical on-line system for data analysis. Doctoral dissertation. The Ohio State University, 1972.

HSIAO, D. K.; MANOLA, F. Data management with variable structure and rapid access. In: Procedings of The First USA-Japan Computer Conference, Sponsored by AFIPS and IPS of Japan, October 1972, Tokyo, Japan.

HSIAO, D. K. Lecture outlines on systems programming. Reproduced in paper-bound form for the students at The Ohio State University, 1972.

HSIAO, D. K. Logical access control mechanisms in computer systems. In: Proceedings of Conference on Secure Data Sharing, sponsored by the Naval Ship Research and Development Center and Office of Naval Research, October 1972, Washington, D.C.

KLIPPERT, J. C. Necessary and sufficient conditions for the uniform convergence of interpolating polynomials to functions in $C_T^*(\omega)$. Doctoral dissertation. The Ohio State University, 1972.

LAY, W. M. The double-KWIC coordinate indexing technique: theory, design, and implementation. Doctoral dissertation. The Ohio State University, 1973.

LEE, Y. H. Asymptotic properties of convolution products of sequences. Doctoral dissertation. The Ohio State University, 1973.

MANOLA, F.; HSIAO, D. K. A model for keyword based file structures and access. NRL Memorandum Report 2544, Naval Research Laboratory, Washington, D.C., January 1973.

MATHIS, B. A. Techniques for the evaluation and improvement of computer-produced abstracts. Doctoral dissertation. The Ohio State University, 1972.

MATHIS, B. A.; MATHIS, H. F. Maximum power transfer from a multiple-terminal network to a single impedance and A symmetrical unitary matrix which transforms a given complex vector into a second given vector. In: Proceedings of the IEEE, 60:6. June 1972.

WEIMAN, C. F. R. Pattern recognition by retina-like devices. Doctoral dissertation. The Ohio State University, 1972.

WHITE, L. J.; JACKSON, D. M. Stability problems in non-statistical classification theory, The Computer Journal, 15:3 (August, 1972) p. 214-221.

WHITTEMORE, B. J. A generalized decision model for the analysis of information. Doctoral dissertation. The Ohio State University, 1972.

YOUNG, C. E. Development and language analysis procedures with application to automatic indexing. Doctoral dissertation. The Ohio State University, 1973.

PAPERS AND BOOKS ACCEPTED FOR PUBLICATION

BOJANIC, R.; VUILLEUMIER, M. Asymptotic properties of linear operators. L'Enseignement Mathematique.

BOJANIC, R.; LEE, Y. H. An estimate for the rate of convergence of convolution products of sequences. SIAM Journal on Mathematical Analysis.

BOJANIC, R.; LEE, Y. H. A survey of recent results and problems in the study of convolution products of sequences. Proceedings of the Approximation Theory Conference, Austin, Texas.

BOJANIC, R. A simple proof of K. Mahler's theorem on approximation of continuous functions of a p-adic variable by polynomials. Journal of Number Theory.

CHANDRASEKARAN, B.; REEKER, L. Artificial intelligence: a case for agnosticism. IEEE Transactions Systems, Man and Cy ernetics.

CHANDRASEKARAN, B.; YOVITS, M. C. Artificial intelligence. Encyclopedia of Computer Science, Marcel Dekker.

CHANDRASEKARAN, B.; JAIN, A. K. Quantization complexity and the mean recognition accuracy. IEEE Transactions on Computers.

HSIAO, D. K. Systems programming. Wesley Publishing Co. Spring 1974.

# APPENDIX G

## TECHNICAL REPORT SERIES

### 1968

YOVITS, M. C.; ERNST, R. L. Generalized information systems: Some consequences for information transfer. October, 1968. 47p. (OSU-CISRC-TR-68-1) (PB-180 929)

FILLMORE, C. J.; LEHISTE, I. Working papers in linguistics no. 2. November, 1968. 128p. (OSU-CISRC-TR-68-3) (PB-182 596)

FRIED, J. B.; LANDRY, B. C.; LISTON, JR., D. M.; PRICE, B. P.; VAN BUSKIRK, R. C.; WASCHSBERGER, D. M. Index simulation feasibility and automatic document classification. October, 1968. 21p. (OSU-CISRC-TR-68-4) (PB-182 597)

ROTHSTEIN, J. Thermodynamics & information: Before, in and beyond quantum mechanics. December, 1968. 21p. (OSU-CISRC-TR-68-5) (PB-183 738)

FINLEY, JR., M. R. The development of a basic language for artificial intelligence. January, 1969. 24p. (OSU-CISRC-TR-68-6) (PB-182 305)

### 1969

COLOMBO, D. S.; RUSH, J. E. Use of word fragments in computer-based retrieval systems. February, 1969. 7+[9]p. (OSU-CISRC-TR-69-1) (PB-184 104)

WHITE, L. J. Minimum covers of fixed cardinality in weighted graphs. March, 1969. 14p. (OSU-CISRC-TR-69-2) (PB-183 737)

JACKSON, D. M. The construction of retrieval environments and pseudo-classifications based on external relevance. April, 1969. 74p. (OSU-CISRC-TR-69-3) (PB-184 462)

ELLIOT, D. E.; HUANG, S.; LANGENDOEN, D. T.; LEE, P. G.; LEHISTE, I. Working papers in linguistics no. 3. June, 1969. 181p. (OSU-CISRC-TR-69-4)

BRIGGS, G. E. Reaction time and uncertainty in human information processing. March, 1969. 36p. (OSU-CISRC-TR-69-5) (PB-184 135)

WHITE, L. J.; RUSH, J. E. Linear lists for spiro graphs. June, 1969. 69p. (OSU-CISRC-TR-69-6) (PB-194 402)

PETRARCA, A. E.; LAY, W. M. The double KWIC coordinate index. A new approach for preparation of high-quality printed indexes by automatic indexing techniques. April, 1969. 12+[17]p. (OSU-CISRC-TR-69-7)

YOVITS, M. C. Information science: Toward the development of a true scientific discipline. June, 1969. 27p. (OSU-CISRC-TR-69-8) (PB-187 983)

PETRARCA, A. E.; LAY, W. M. The double KWIC coordinate index. II. Use of an automatically generated authority list to eliminate scattering caused by some singular and plural main index terms. August, 1969. 13p. (OSU-CISRC-TR-69-9)

MCCULLOUGH, J. L. The acquisition of information across cultures: I. Persuasive role play, counterargument and attitude change. August, 1969. 18p. (OSU-CISRC-TR-69-10) (PB-197 568)

ERNST, R. L.; YOVITS, M. C. Information science as an aid to decision making. September, 1969. 22p. (OSU-CISRC-TR-69-13) (PB-189 666)

LANDRY, B. C. An indexing and re-indexing simulation model. June, 1969. 50p. (OSU-CISRC-TR-69-14) (PB-198 115)

SALVADOR, R. Automatic abstracting and indexing. June, 1969. 93p. (OSU-CISRC-TR-69-15)

STEVENS, D. W. A computer program for the reduction of flow tables. June, 1969. 97p. (OSU-CISRC-TR-69-16) (PB-189 679)

COLOMBO, D. S. Automatic retrieval systems and associated retrieval languages. 1969. 69p. (OSU-CISRC-TR-69-17) (PB-198 116)

SCHLESSINGER, J. D.; WHITE, L. J. Optimum prefix encoding. August, 1969. 85p. (OSU-CISRC-TR-69-18) (PB-198 117)

DAY, R.; WHITE, L. J. Hebbian neural simulation: Computer program documentation. (OSU-CISRC-TR-69-19) (PB-204 003)

REEKER, L. H. Extended finite state representation of infinite machines. September, 1969. 36p. (OSU-CISRC-TR-69-20) (PB-187 949)

WILLIAMS, N. T.; ERNST, R. L. A computer simulation of human short-term memory. 1969. 62p. (OSU-CISRC-TR-69-22) (PB-197 874)

BEZDEK, R. R. The acquisition of information across cultures: II. Social science research in a different culture. III. Cross-cohort activity and attitude change, by J. L. McCullough. January, 1970. 36p. (OSU-CISRC-TR-69-23) (PB-197 876)

1970

UNKLESBAY, M. K. A one step version of younger's algorithm for bounded context grammars. 1970. 41p. (OSU-CISRC-TR-70-1) (PB-197 603)

LI, Y. Information structure and optimal policy. September, 1970. 18p. (OSU-CISRC-TR-70-2) (PB-197 605)

DILLON, S. R. Some procedures for finding substitution property partitions, substitution property covers, and cover pairs for finite state sequential machines. 1970. 79p. (OSU-CISRC-TR-70-3) (PB-197 643)

MATHIS, B. A.; WHITE, L. J.; JACKSON, D. M. Stability analysis of term similarities for information classification theory. July, 1970. 79p. (OSU-CISRC-TR-70-4) (PB-195 376)

MCGHEE, R. B.; DILLON, S. R. A paull-unger procedure for substitution property partitions. April, 1970. 16p. (OSU-CISRC-TR-70-5) (PB-192 120)

DAY, R. G.; WHITE, L. J. Study of a random search method for function minimization. March, 1970. 77p. (OSU-CISRC-70-6) (PB-194 404)

PHARES, R.; WHITE, L. J. Identification of circuits in chemical structures. June, 1970. 73p. (OSU-CISRC-TR-70-7) (PB-194 396)

HARALSON, K. M.; WHITE, L. J. Optimal prefix codes for ensembles of N equiprobable messages using a binary alphabet. May, 1970. 105p. (OSU-CISRC-TR-70-8) (PB-197 642)

PETRARCA, A. E.; LAITINEN, S. V.; LAY, W. M. Use of the double KWIC coordinate indexing technique for chemical line notations. 1970. 14+[17]p. (OSU-CISRC-TR-70-9) (PB-198 269)

LAY, W. M.; PETRARCA, A. E. Modified double KWIC coordinate index. Refinements in main term and subordinate term selection. 1970. 11+[11]p. (OSU-CISRC-TR-70-10) (PB-197 567)

LYONS, J. J. The speed-accuracy trade-off in processing different classes of material. 1970. 38p. (OSU-CISRC-TR-70-11) (PB-198 114)

FILLMORE, C. J.; LEHISTE, I.; MELTZER, D.; TATHAM, M. A.; THOMPSON, S. A. Working papers in linguistics no. 6. September, 1970. 132p. (OSU-CISRC-TR-70-12) (PB-194 829)

ROTHSTEIN, J. Information generalization of entropy in physics. February, 1970. 22p. (OSU-CISRC-TR-70-24) (PB-192 128)

JACKSON, D. M. Basis for an improvability measure for retrieval performance. February, 1970. 31p. (OSU-CISRC-TR-70-25) (PB-197 812)

DRACHMAN, B.; EDWARDS, M. L.; FILLMORE, C. J.; LEE, G.; LEE, P.; LEHISTE, I.; ZWICKY, A. M. Working papers in linguistics no. 4 May, 1970. 164p. (OSU-CISRC-TR-70-26) (PB-192 163)

## 1971

ROTHSTEIN, J. Patterns and algorithms. January, 1971. 8p. (OSU-CISRC-TR-71-1) (PB-197 604)

GROSU, A.; LEE, G. Working papers in linguistics no. 7. February, 1971. [243]p. (OSU-CISRC-TR-71-2) (PB-198 278)

CHANDRASEKARAN, B.; KANAL, L. On linguistic, statistical, and mixed models for pattern recognition. March, 1971. 33,A5p. (OSU-CISRC-TR-71-3) (PB-198 279)

WHITTEMORE, B. An example of the application of generalized information systems concepts to the quantification of information in a decision system: The examination of quantified information flow in an industrial control problem. May, 1971. 51p. (OSU-CISRC-TR-71-4) (PB-202 621)

OSTROM, T. M.; STEELE, C. M.; SMILANSKY, J. Information and attitudes: The effects of information context and perceived discrepancy on attitudes. May, 1971. 23p. (OSU-CISRC-TR-71-5) (PB-202 622)

LI, Y. Equipment replacement models: A generalization and extension. May, 1971. 17p. (OSU-CISRC-TR-71-6) (PB-200 548)

ELLIOTT, D.; GEIS, M.; GROSU, A.; NOBEL, B.; ZWICKY, ANN; ZWICKY, ARNOLD. Working papers in linguistics no. 8. June, 1971. 197p. (OSU-CISRC-TR-71-7) (PB-202 724)

BOND, Z. S.; GREGORSKI, R.; KEREK, A.; LEHISTE, I.; SHOCKEY, L.; WENDELL, M. V. Working papers in linguistics no. 9. July, 1971. 232p. (OSU-CISRC-TR-71-8) (PB-204 002)

JOHNSEN III, A. M. Performance in memory scan task under conditions of fixed versus varied memory sets. November, 1971. 49p. (OSU-CISRC-TR-71-9)

MEHAFFEY III, L. The spectral sensitivity of the turtle Pseudemys scripta elegans. November, 1971. 89p. (OSU-CISRC-TR-71-10)

WILLIAMS, J. D. Stimulus encoding and human information processing. November, 1971. 65p. (OSU-CISRC-TR-71-11)

SANDERS, S. A. A modification of a method of generating random numbers using a combination of two congruential generators. December, 1971. 76p. (OSU-CISRC-TR-71-12)

LANDRY, B. C. A theory of indexing: Indexing theory as a model for information storage and retrieval. December, 1971. 271p. (OSU-CISRC-TR-71-13) (PB-205 829)

OSTROM, T. M.; EDWARDS, J. D.; ROSENBLOOD, L. K. Integration of discrepant information in interpersonal attitudes. December, 1971. 43p. (OSU-CISRC-TR-71-14)

## 1972

WHITE, L. J.; GILLENSON, M. L. Optimum center location. January, 1972. 69,A6,B32p. (OSU-CISRC-TR-72-1)

MELTZER, D. Speech synthesis by haar functions with comparison to a terminal analog device. January, 1972. 135p. (OSU-CISRC-TR-72-2)

CHANDRASEKARAN, B.; JAIN, A. K. Quantization of independent measurements and recognition performance. March, 1972. 14p. (OSU-CISRC-TR-72-3)

CAMERON, J. S. Automatic document pseudoclassification and retrieval word frequency techniques. March, 1972. 165p. (OSU-CISRC-TR-72-4)

OSTROM, T. M.; SLOAN, L. R.; MCCULLOUGH, J. L. Information and attitudes: The effects of repetition and amount of information. April, 1972. 38p. (OSU-CISRC-TR-72-5) (PB-209 802)

LEHISTE, I.; MELTZER, D.; SHOCKEY, L.; GREGORSKI, R. Working papers in linguistics no. 12. June, 1972. 88p. (OSU-CISRC-TR-72-6) (PB-210 781)

EKONG, V. J. U. Rate of convergence of hermite interpolation based on the roots of certain Jocabi polynomials. June, 1972. 54p. (OSU-CISRC-TR-72-7) (PB-211 237)

WEIMAN, C. F. R.; ROTHSTEIN, J. Pattern recognition by retina-like devices. July, 1972. 154p. (OSU-CISRC-TR-72-8) (PB-211 238)

CHANDRASEKARAN, B.; REEKER, L. H. Artificial intelligence - a case for agnosticism. August, 1972. 28p. (OSU-CISRC-TR-72-9)

ROTHSTEIN, J. Loschmidts's and Zermelo's paradoxes do not exist. October, 1972. 9p. (OSU-CISRC-TR-72-10)

YOVITS, M. C.; CHANDRASEKARAN, B. Artificial intelligence. December, 1972 39p. (OSU-CISRC-TR-72-11)

HSIAO, D. K.; DENICOFF, M.; BERGART, J. G. An annotated and cross-referenced bibliography on computer security and access control in computer systems. November, 1972. 57p. (OSU-CISRC-TR-72-12)

FOULK, C. R.; JUELICH, O. C. Smooth programs and languages. November, 1972. 16p. (OSU-CISRC-TR-72-13)

YOVITS, M. C.; WHITTEMORE, B. A generalized conceptual development for the analysis and flow of information. 31p. (OSU-CISRC-TR-72-14)

MATHIS, B. A. Techniques for the evaluation and improvement of computer-produced abstracts. December 1972. 262p. (OSU-CISRC-TR-72-15)

1973

LAY, W. M. The double KWIC coordinate indexing technique: theory, design, and implementation. February 1973. 250p. (OSU-CISRC-TR-73-1)

YOUNG, C. E. Development of language analysis procedures with application to automatic indexing. April 1973. 298p. (OSU-CISRC-TR-73-2)

STRONG, S. M. An algorithm for generating structual surrogates of English text. April 1973. 140p. (OSU-CISRC-TR-73-3)

INVESTIGATOR INDEX

Abilock, J. G., 12

Atwell, R., 23

Baum, R., 24

Biermann, A. W., 24

Blackwell, H. R., 18

Bojanic, R., 19, 20, 21

Chan, P., 17

Chandrasekaran, B., 14, 15, 17

Chiou, W., 18

Craig, C. S., 28

Ernst, R. L., 11

Foulk, C. R., 25, 26

Gelperin, D., 14

Gillenson, M. L., 16

Griffith, W., 23

Hasbrouck, C., 23

Hepler, S., 11

Hsiao, D. K., 24, 25, 26, 27

Jain, A. K., 14

Juelich, O. C., 25

Kalmey, D. L., 18

Kearns, C. H., 22

Kerr, D. S., 18, 21, 24

Kirsch, B., 23

Kirschen, D., 23

Krishnaswamy, R. 24

LaGreca, A. J., 28

Lam, C. C., 15

Lange, O., 26

Lay, W. M., 10

Lazorik, G. J., 28

Lee, M. J., 28

Leggett, E. W., 26

Mathis, R. F., 23

McCauley, E. J., 25

Nee, C. J., 27

Petrarca, A. E., 10

Petry, F. E., 24

Rothstein, J., 16, 17

Roulier, J. A. 20

Rush, J. E., 11

Salem, R. G. 28

Senta, E., 21

Shapiro, A., 15

Shisha, O., 19

Stalcup, W. S. 10

Stern, L. W., 28

Su, H. Y., 26

Wang, P., 21

Weiman, C. F. R., 16

White, L. J., 11, 18, 21

Wyrick, T., 24

Yovits, M. C. 12

SUBJECT INDEX

Academic Programs, 4

Activities, Related, of CISRC Staff, 41

Approximation of Convex Functions, 20

Approximation by Discrete Positive Linear Operators, 19

Artificial Intelligence, 14

Automatic Indexing, 10

Automatic Program Synthesis, 24

Automatic Theorem Proving, 14

Binary Code and Associated Cellular Automata for Pattern Recognition, 16

Biological Systems, Information Processing in, 18

Cellular Automata, 16

CISRC Senior Personnel 37

Classification Technique, a Sequential Analysis, 11

Computer Flowgraphs, a Smoothness Index for, 26

Computer graphics, 22

Computer Network, Local, 24

Computer Program Debugging, 23

Computer Programs, Parallelism in, 25

Context Protection, 27

Course Offerings, 7, 30

Cryptography and Security Structures, 23

Current Awareness Service, Diffusion of, 28

Data Base, Graphical Model of Functional Dependences in a Relational, 24

Data Secure Systems, 25, 27

Debugging, 23

Decision Theory, Finite Memory, 15

Decision Theory for Pattern Recognition, 14

Diffusion of MIC Current Awareness Services, 28

Dimensionality Reduction for Pattern Recognition, 15

Doctoral Degrees, 8

Equations, Algorithms for Solving Nonlinear Systems of, 18

Face Generation Paradigm, 17

Facilities of CISRC, 2

Faculty, 7, 33

Finite Memory Decision Theory, 15

Flowgraphs, a Smoothness Index for Computers, 27

Functional Dependences in a Relational Data Base, Graphical Model of, 24

Graphical Model of Functional Dependencies in a Relational Data Base, 24

General Theory of Information Flow and Analysis, 12

Graduate Programs, 6

Graphics, Computer, 22

Growth of Dept. of Computer and Information Science, 5

Hierarchical Pattern Generation, Interactive, 16

Human Information Processing, 11

Indexing, Automatic, 10

Information Analysis, 12

Information Flow and Analysis, A General Theory of, 12

Information Processes in Biological, Systems, 18

Information Processing, Human, 11

Information Storage and Retrieval, 10

I R System Management Decision-Making, 28

Local Computer Network, 24

Man-Machine Interactive Programming System, 24

Management Game for I R System Management Decision-Making, 28

Matrices, Sparce, 21

Mechanized Information Center, Joint Program with, 28

Memory, Finite, 15

Memory Functions, Human, 11

Memory, Transfer Processes in, 11

MIC, 28

Modeling of Data Secure Systems, 25

Network, Local Computer, 24

Nonlinear Systems of Equations, Algorithms for Solving, 18

Objectives of CISRC, 1

Optimization for Virtual Memory, Program, 26

Organization of CISRC, 1

Parallelism in Computer Programs, 25

Pattern Generation, Interactive Hierarchical, 16

Pattern Recognition by Parallel Computation, 16

Pattern Recognition, Dimensionality Reduction for, 15

Personnel, CISRC, 37

Program Optimization for Virtual Memory, 26

PL/X Compiler, 26

Psychophysics, Visual, 18

Publications of CISRC Staff, 48

Regularly Varying Sequences, A Unified Theory, 21

Reports, Technical, 9, 51

Retrieval System Management Game, 28

Scope of Computer and Information Science Program, 2

Secure Systems, Modeling of Data, 25

Security Structures, Cryptography, and, 23

Seminar Series, Computer and Information Science, 38

Sequences, A Unified Theory of Regularly Varying, 21

Sequential-Analysis Classification Technique, 11

Smoothness Index for Computer Flowgraphs, 26

Sparse Matrices, 21

Sociological Research on Current Awareness Service, 28

Storage and Retrieval System Management Game, 28

Symmetric Ternary Number System, 17

System Programming, 22

Technical Reports, 9, 51

Ternary Number System, Symmetric, 17

Undergraduate Programs, 4

Virtual Memory, Program Optimization
for, 26

Visual Psychophysics, 18